JIDC | THE JOURNAL OF INFECTION IN DEVELOPING COUNTRIES

Original Article

Global burden of respiratory infections and tuberculosis attributable to risk factors, 1990–2021: demographic and SDI analysis

Shareli Caikai[1], Jing Jiang[1], Yi Shi[1], Hongli Zhang[1], Sicheng Xu[1]

[1] Department of Respiratory Intensive Care Unit, First Affiliated Hospital of Xinjiang Medical University, Urumqi, Xinjiang, 830011, China

Abstract

Introduction: Respiratory infections and tuberculosis are leading causes of global morbidity and mortality; yet comprehensive research on their associated risk factors remains limited, hindering the development of effective preventive strategies.

Methodology: The 2021 Global Burden of Disease data from 204 countries (1990–2021) was used to measure deaths, disability-adjusted life years (DALYs), and their age-standardized rates (ASMR and ASDR) tied to 9 risk factors. The trends were analyzed by age, gender, and socio-demographic index (SDI) regions, with annual and average annual percentage changes (APC, AAPC) used to track changes over time.

Results: Globally, mortality rates (ASMR) for respiratory infections and tuberculosis linked to traditional risks—malnutrition, air pollution, and alcohol use—declined significantly; annual decreases of 4.46%, 3.18%, and 3.35%, respectively. Deaths attributed to metabolic risks like high BMI and blood sugar increased, despite falling ASMR. Geographic disparities were notable: Lesotho saw the sharpest rise in BMI-related mortality (3.92%), while Hungary had the steepest decline (−7.4%). Men faced a higher burden from behavioral risks, with tobacco-related mortality 3.6 times higher than in women. Children under 5 years were especially vulnerable to environmental risks, with unsafe water and sanitation contributing to a 4.55% annual decline in mortality rates.

Conclusions: This study highlights the need for targeted actions, such as tobacco control in high-middle SDI regions, air quality improvements in South Asia, and nutrition programs in Sub-Saharan Africa. It offers a precise public health framework to reduce respiratory infections and tuberculosis, and promote global health equity by analyzing sociodemographic and time trends.

Key words: respiratory infections and tuberculosis; risk factors; global burden of disease; socio-demographic index; health disparities.

J Infect Dev Ctries 2026; 20(7):974-989. doi:10.3855/jidc.21667

(Received 27 March 2025 – Accepted 04 August 2025)

Introduction

Respiratory infections and tuberculosis, remain major global health challenges, contributing substantially to morbidity and mortality worldwide [1,2]. The burden of these diseases is further compounded by environmental exposures and persistent socioeconomic inequities [3]. However, the associations between respiratory infections and modifiable risk factors, particularly across diverse demographic and geographic contexts, remain poorly understood. Critical gaps persist in understanding how specific risk factors disproportionately affect populations across age, gender, and geographic regions; hindering the development of tailored and equitable public health strategies.

Existing evidence highlights 9 key risk factors—child and maternal malnutrition [4], air pollution [1,5], tobacco use [6], unsafe water and sanitation [7], high body mass index (BMI) [8], high fasting plasma glucose (FPG) [9,10], dietary risks [2,11], physical inactivity [12], and alcohol use [13]—as major contributors to respiratory infections and tuberculosis burden. Recent studies have quantified the population-level impacts of various risk factors, highlighting the effects of alcohol use, tobacco use, dietary risks, high BMI, elevated FPG, and physical inactivity on tuberculosis incidence. However, these studies have not systematically assessed all risk factors associated with respiratory infections and tuberculosis, nor have they comprehensively analyzed differences by age, gender, socio-demographic index (SDI), and geographic regions [14,15].

The variation in risk factor impacts across socioeconomic strata, age groups, and gender remains inadequately characterized, limiting the development of tailored interventions. For example, the highest prevalence and frequency of cigarette smoking in many low- and middle-income countries (LMICs) are consistently observed among men, individuals with lower levels of education, those with reduced household wealth, residents of rural areas, and older age groups [16,17]. Meanwhile, malnutrition remains a persistent and disproportionate burden in low-resource settings [3,18], exacerbating health inequities and contributing to a dual burden of disease in populations already facing challenges related to poverty and limited access to

healthcare [19,20]. Concurrently, gender-based disparities in behavioral risks (e.g., alcohol consumption, tobacco use) [21,22], and age-specific vulnerabilities to environmental exposures (e.g., household and ambient air pollution), remain insufficiently mapped globally [23,24]. These evidence gaps constrain the precision of public health strategies aimed at mitigating inequities in respiratory infections and tuberculosis. Addressing these disparities requires disaggregated, context-specific data to elucidate how risk factor profiles intersect with socioeconomic development, demographic shifts, and healthcare access.

To this end, a comprehensive analysis of the global, regional, and national burden of respiratory infections and tuberculosis attributable to risk factors from 1990 to 2021 was conducted, by integrating data from 204 countries and territories. The methodologies from the Global Burden of Disease (GBD) 2021 study were used to quantify age-standardized trends, evaluate correlations with the SDI, and stratify outcomes by age, gender, and geography. The findings reveal pronounced declines in age-standardized mortality rates (ASMR) and age-standardized disability-adjusted life years (DALYs) rates (ASDR) for traditional risks, but escalating burdens from metabolic factors. These disparities are driven by socioeconomic development, demographic factors, and regional policies.

This study advances the mechanistic understanding of risk modulation in respiratory infections and tuberculosis and provides actionable insights for tailoring interventions to vulnerable populations, thereby addressing persistent inequities in the global health landscape.

Methodology

The GBD 2021 study analyzed 288 diseases, injuries, and risk factors across 204 countries (1990–2021) using metrics including incidence, prevalence, mortality, and DALYs [25,26]. The SDI; which integrates measures of fertility, education, and income; divides regions into 5 distinct groups: low, low-middle, middle, high-middle, and high. In the International Classification of Diseases, Tenth Revision (ICD-10), respiratory infections and tuberculosis are classified under the codes A10-A14, A15-A19.9, A48.1, A70, B34.2, B90-B90.9, B97.2, B97.4-B97.6, H70-H70.9, J00-J02.8, J03-J03.8, J04-J04.2, J05-J05.1, J06.0-J06.8, J09-J15.8, J16-J16.9, J20-J21.9, J36-J36.0, J91.0, K67.3, K93.0, M49.0, N74.1, P23.0-P23.4, P37.0, U04-U04.9, U07-U07.2, U84.3. In the Ninth Revision (ICD-9), these conditions are classified under the codes 010-019.9, 034.0, 079.6, 137-137.9, 138.0-138.9, 320.4, 381-383.9, 460-464.4, 464.8-464.9, 465.0-465.8, 466-469, 470.0, 475-475.9, 476.9, 480-482.8, 483.0-483.9, 484.1-484.2, 484.6-484.7, 487-489, 730.4-730.6.

Exposure assessment

The nine risk factors for respiratory infections and tuberculosis are defined by GBD 2021 methods appendices [26].

Air pollution encompasses particulate matter, ambient ozone, and nitrogen dioxide. Physical inactivity is defined as total activity below 3,600–4,400 metabolic equivalent (MET)-minutes per week in adults aged > 25 years, derived from frequency, duration, and intensity across occupational, domestic, and recreational domains. Unsafe water, sanitation, and handwashing were classified according to the World Health Organization/United Nations Children's Fund (WHO/UNICEF) Joint Monitoring Program criteria, which distinguish improved sources (e.g., piped water, boreholes) from unimproved sources (e.g., surface water).

Metabolic risks included high FPG > 4.9–5.3 mmol/L and BMI > 20–23 kg/m² in adults, and overweight/obesity in children (per the International Obesity Task Force standards). Tobacco use was assessed via nationally representative surveys of self-reported current or former use (daily/occasional) among individuals aged > 10 years, excluding non-tobacco products. High alcohol use was defined as consumption exceeding the theoretical minimum risk exposure level.

Child and maternal nutritional deficiencies were modeled using mortality data from vital registration systems, verbal autopsies, and surveillance reports. Dietary risks included 6 components: low intake of whole grains (< 160–210 g/day) and fruits/vegetables (< 340–350 g/day); and high consumption of sugar-sweetened beverages (> 0 g/day), unprocessed red meat (> 0–200 g/day), and processed meats (> 0 g/day).

Statistical analysis

Metrics including the number of deaths, DALYs, ASMR, and ASDR were analyzed to assess temporal trends and disparities in mortality and disease burden across age groups, genders, regions, and populations. These metrics enable comparisons by adjusting for variations in population age structures. Temporal trends in ASMR and ASDR were quantified using average annual percentage change (AAPC) estimates derived from Joinpoint regression analysis (Joinpoint Software, version 5.0.2). The AAPC, which summarizes the average trend over the entire study period, was

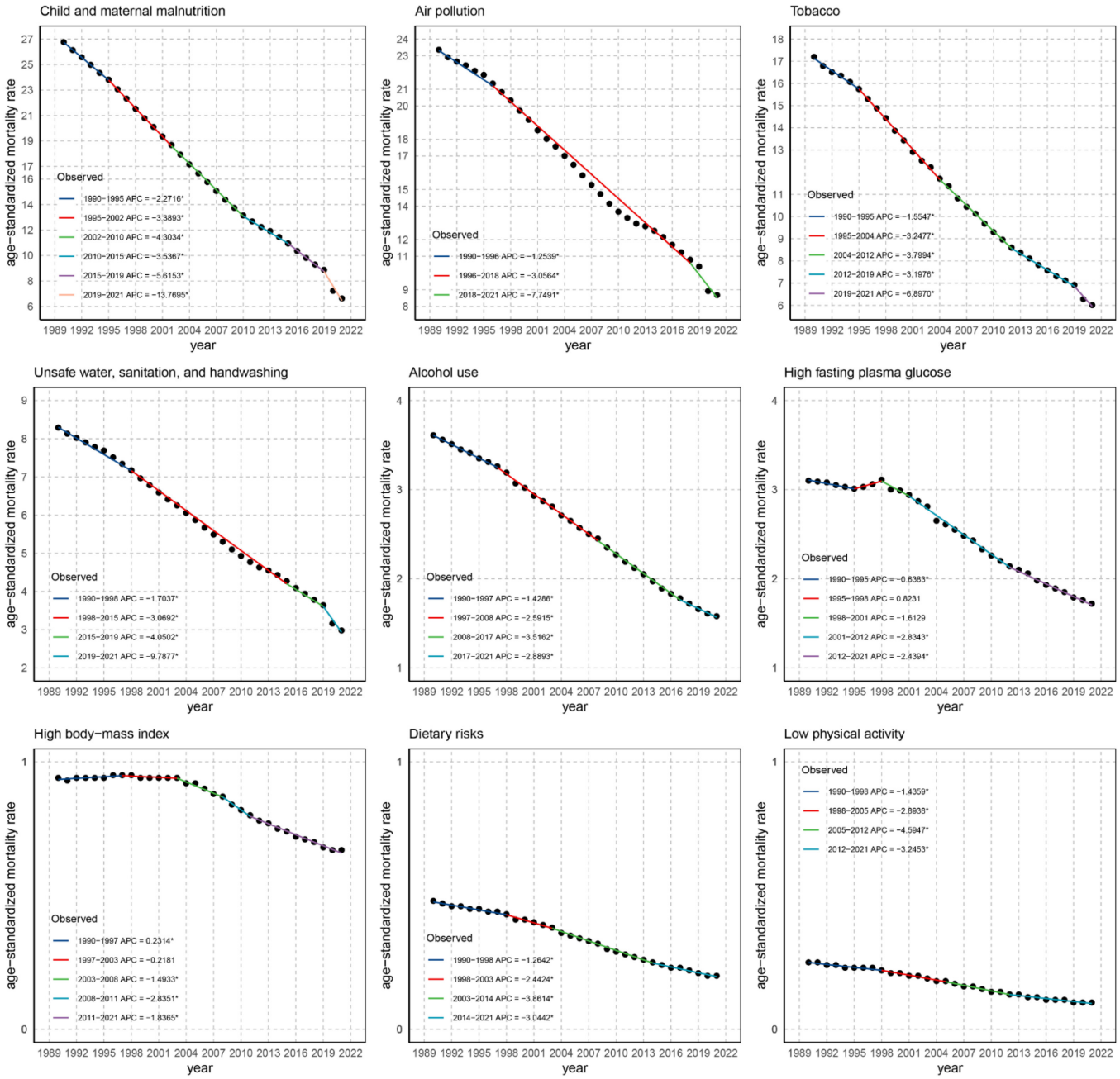
calculated as a geometrically weighted average of the segment-specific APC estimates derived from the final selected Joinpoint model. A maximum of 5 joinpoints were permitted to model nonlinear trends, with statistical significance determined through permutation testing ($\alpha = 0.05$) and parametric methods.

Results

Global and regional trends in respiratory infections and tuberculosis burden attributable to risk factors, 1990–2021

Globally and across all SDI regions, ASMR for respiratory infections and tuberculosis attributable to key risk factors decreased substantially between 1990 and 2021 (Figure 1). Child and maternal malnutrition; air pollution; tobacco use; and inadequate water, sanitation, and hygiene (WASH) facilities were the

Figure 1. Global trends in age-standardized mortality rates (ASMR) from respiratory infections and tuberculosis attributable to risk factors, and annual percent change (APC), 1990–2021.



leading contributors. Notably, the ASMR decline attributable to these factors accelerated in recent years, with APC reaching – 13.77% for malnutrition, 2019–2021; – 7.75% for air pollution, 2018–2021; – 6.90% for tobacco, 2019–2021; and – 9.79% for WASH, 2019–2021 (Figure 1).

The AAPC in ASMR for respiratory infections and tuberculosis varied across risk factors. Child and maternal malnutrition had the steepest reduction (AAPC: − 4.46%, 95% CI: − 4.54% to − 4.39%), followed by tobacco use (− 3.35%, 95% CI: − 3.46% to − 3.24%) and air pollution (− 3.18%, 95% CI: − 3.41% to − 2.94%) (Table 1). Globally, the absolute numbers of deaths from respiratory infections and tuberculosis attributable to risk factors generally showed a downward trend, except for high BMI and FPG. The number of deaths caused by these two risk factors increased from 38,272.23 (95% UI: 8,106 to 107,541.75) in 1990 to 57,447.18 (12,864.18 to 150,516.82) for high BMI, and from 117,710.02 (84,376.47 to 153,985.34) in 1990 to 147,222.60 (106,967.98 to 195,819.47) for high FPG. Despite these increases in absolute numbers, the ASMR caused by high BMI and FPG decreased by approximately 28.7% and 44.5%, respectively. Globally, ASDR for respiratory infections and tuberculosis due to various risk factors significantly declined over the last 3 decades, consistently across all SDI regions, with the most evident reductions in high-middle SDI regions. The AAPC in ASDR varied by risk factor. Specifically, child and maternal malnutrition had the largest decline (AAPC: − 4.46%, 95% CI: − 4.54% to − 4.39%), notably followed by tobacco use (− 4.07%, 95% CI: − 4.16% to − 3.97%) and air pollution (− 4.01%, 95% CI: − 4.24% to − 3.78%). Additionally, high BMI had the slowest decline (− 0.69%, 95% CI: − 0.81% to − 0.58%) (Table 2). Despite global increases in DALYs due to BMI and high FPG, DALYs attributable to other risk factors mainly decreased. Specifically, DALYs due to high BMI increased from 1,296,112 (95% UI: 256,345 to 3,776,109) in 1990 to 2,066,810 (95% UI: 446,316 to 5,536,306) in 2021, and DALYs due to high FBG increased from 3,057,450 (95% UI: 2,196,852 to 4,068,063) in 1990 to 3,736,487 (95% UI: 2,709,577 to 4,972,204) in 2021.

National disparities in respiratory infections and tuberculosis burden attributable to risk factors across 204 countries and territories, 1990–2021

Significant geographic disparities were observed in the AAPC of ASMR attributable to various risk factors. The AAPC in ASMR showed a downward trend in most countries (Figure 2). Argentina exhibited the largest upward trend in ASMR due to air pollution (AAPC: 0.97, 95% CI: 0.16 to 1.78), while Finland showed the steepest decline (−10.39, 95% CI: − 13.4 to − 7.29). Iran had the highest increase for alcohol use (34.51, 95% CI: 30.25 to 38.91), whereas Sudan recorded the largest reduction (− 30.39, 95% CI: − 32.9 to − 27.79). Child and maternal malnutrition-related ASMR increased most in Tokelau (2.72, 95% CI: 0.69 to 4.78), but decreased sharply in Iran (− 11.48, 95% CI: − 12.1 to − 10.85). Dietary risks drove the largest ASMR rise in Lesotho (2.43, 95% CI: 1.99 to 2.88), while the Maldives achieved the greatest decline (− 7.5, 95% CI: − 7.87 to − 7.13).

Table 1. Annual average percentage change (AAPC) in age-standardized mortality rates of respiratory infections and tuberculosis attributable to nine risk factors, by age, gender, socio-demographic index (SDI), and regions, 1990–2021 (95% CI).

Characteristics	Air pollution	Alcohol use	Child and maternal malnutrition	Dietary risks	High body-mass index
Global	-3.18 (-3.41 to -2.94)	-2.64 (-2.7 to -2.57)	-4.46 (-4.54 to -4.39)	-2.78 (-2.89 to -2.67)	-1.1 (-1.25 to -0.95)
Gender					
Female	-3.41 (-3.66 to -3.16)	-2.65 (-2.71 to -2.59)	-4.68 (-4.89 to -4.47)	-2.41 (-2.59 to -2.24)	-0.96 (-1.14 to -0.77)
Male	-3.01 (-3.21 to -2.81)	-2.67 (-2.76 to -2.59)	-4.31 (-4.37 to -4.25)	-3.07 (-3.18 to -2.95)	-1.25 (-1.36 to -1.14)
SDI					
Low SDI	-2.42 (-2.71 to -2.13)	-2.41 (-2.57 to -2.25)	-4.64 (-4.75 to -4.53)	-2.38 (-2.51 to -2.24)	-0.69 (-0.79 to -0.58)
Low-middle SDI	-2.86 (-3.17 to -2.55)	-2.38 (-2.55 to -2.2)	-4.76 (-5 to -4.51)	-2.87 (-3.24 to -2.49)	-0.87 (-1.07 to -0.66)
Middle SDI	-4.06 (-4.35 to -3.76)	-3.5 (-3.71 to -3.3)	-6.25 (-6.44 to -6.06)	-3.77 (-3.86 to -3.67)	-2.02 (-2.17 to -1.87)
High-middle SDI	-4.02 (-4.39 to -3.65)	-4.73 (-5.04 to -4.41)	-8.33 (-8.59 to -8.07)	-4.31 (-4.68 to -3.94)	-2.69 (-3.11 to -2.27)
High SDI	-3.38 (-4.08 to -2.68)	-5.59 (-5.75 to -5.42)	-6.58 (-6.95 to -6.21)	-3.95 (-4.15 to -3.76)	-3.4 (-3.56 to -3.24)
Region					
Australasia	-1.75 (-3.26 to -0.22)	-4.18 (-4.64 to -3.71)	-6.08 (-7.25 to -4.9)	-3.53 (-5.54 to -1.48)	-3.23 (-3.68 to -2.78)
Oceania	-1.91 (-2.03 to -1.78)	-2.22 (-2.4 to -2.05)	-2.06 (-2.4 to -1.72)	-1.92 (-2.14 to -1.7)	-1.37 (-1.63 to -1.12)
East Asia	-6.09 (-6.38 to -5.79)	-6.14 (-6.46 to -5.81)	-9.39 (-9.68 to -9.09)	-5.9 (-6.13 to -5.67)	-4.01 (-4.37 to -3.66)
Central Asia	-3.41 (-3.9 to -2.92)	-2.86 (-3.61 to -2.12)	-5.25 (-5.54 to -4.97)	-1.4 (-1.7 to -1.1)	-1.5 (-1.82 to -1.18)
South Asia	-2.89 (-3.23 to -2.54)	-2.83 (-3.19 to -2.46)	-4.48 (-4.8 to -4.16)	-3.19 (-3.33 to -3.05)	-1.12 (-1.27 to -0.96)
Southeast Asia	-2.98 (-3.1 to -2.87)	-1.45 (-1.61 to -1.3)	-5.74 (-5.83 to -5.64)	-3.31 (-3.38 to -3.23)	-1.41 (-1.5 to -1.33)
High-income Asia Pacific	-3.16 (-3.62 to -2.69)	-6.3 (-6.8 to -5.8)	-7.12 (-7.72 to -6.51)	-4.82 (-5.05 to -4.6)	-4.3 (-4.62 to -3.98)
Eastern Europe	-2.54 (-3.89 to -1.17)	-2.13 (-3.07 to -1.19)	-6.24 (-6.97 to -5.5)	-3.28 (-3.96 to -2.6)	-0.23 (-1.07 to 0.61)
Central Europe	-2.91 (-3.63 to -2.19)	-4.62 (-5.32 to -3.91)	-7.17 (-7.94 to -6.4)	-3.12 (-3.71 to -2.53)	-3.78 (-4.49 to -3.06)
Western Europe	-4.18 (-5.17 to -3.19)	-5.57 (-5.96 to -5.17)	-6.13 (-6.92 to -5.32)	-4.85 (-5.31 to -4.38)	-4.5 (-5 to -4.01)
High-income North America	-5.46 (-5.97 to -4.94)	-4.18 (-4.51 to -3.85)	-4.53 (-5.47 to -3.58)	-3.97 (-4.31 to -3.62)	-4.28 (-4.67 to -3.89)
Andean Latin America	-3.79 (-4.13 to -3.44)	-5.68 (-6.49 to -4.86)	-7.82 (-8.43 to -7.2)	-4.79 (-5.3 to -4.28)	-4.22 (-4.76 to -3.68)
Central Latin America	-4.14 (-4.59 to -3.68)	-5.27 (-5.6 to -4.95)	-5.65 (-6.17 to -5.13)	-5.15 (-5.48 to -4.82)	-4.34 (-4.62 to -4.05)
Southern Latin America	-1.32 (-2.57 to -0.06)	-4.57 (-5.42 to -3.7)	-6.59 (-7.93 to -5.22)	-2.6 (-3.22 to -1.98)	-2.94 (-3.81 to -2.05)

Tropical Latin America	-3.32 (-4.06 to -2.57)	-3.45 (-3.69 to -3.21)	-8.85 (-9.25 to -8.44)	-1.87 (-2.13 to -1.6)	-1.75 (-1.95 to -1.56)
Caribbean	-1.92 (-2.31 to -1.52)	-2.6 (-2.88 to -2.31)	-3.22 (-3.49 to -2.95)	-2.1 (-2.56 to -1.64)	-0.7 (-1.07 to -0.34)
North Africa and Middle East	-3.05 (-3.26 to -2.84)	-6 (-6.18 to -5.83)	-6.47 (-6.7 to -6.24)	-3.72 (-3.81 to -3.62)	-3.14 (-3.24 to -3.05)
Eastern Sub-Saharan Africa	-2.57 (-2.69 to -2.46)	-2.65 (-2.8 to -2.51)	-5.62 (-5.89 to -5.35)	-2.51 (-2.62 to -2.41)	-0.72 (-0.86 to -0.57)
Central Sub-Saharan Africa	-1.57 (-1.64 to -1.49)	-1.95 (-2.1 to -1.79)	-6 (-6.14 to -5.86)	-1.83 (-2.03 to -1.64)	0.28 (0.11 to 0.45)
Southern Sub-Saharan Africa	-1.4 (-1.67 to -1.13)	-1.26 (-1.8 to -0.72)	-3.19 (-3.59 to -2.78)	0.17 (-0.46 to 0.81)	0.91 (0.28 to 1.53)
Western Sub-Saharan Africa	-2.15 (-2.25 to -2.05)	-2.44 (-2.66 to -2.22)	-4 (-4.22 to -3.77)	-1.74 (-1.89 to -1.59)	-0.56 (-0.75 to -0.37)
Age (years)					
0-4	-4.76 (-5 to -4.52)	NA	-4.62 (-4.94 to -4.31)	NA	NA
5-9	-3.61 (-4.15 to -3.07)	NA	NA	NA	NA
10-14	-2.42 (-3.05 to -1.8)	NA	NA	NA	NA
15-19	-1.87 (-2.09 to -1.64)	-1.75 (-1.97 to -1.53)	NA	NA	NA
20-24	-1.45 (-1.65 to -1.25)	-1.79 (-2.01 to -1.58)	NA	NA	NA
25-29	-1.36 (-1.59 to -1.12)	-1.7 (-2.03 to -1.37)	NA	-1.03 (-1.42 to -0.63)	0.9 (0.69 to 1.12)
30-34	-1.57 (-1.95 to -1.17)	-2.05 (-2.33 to -1.76)	NA	-1.27 (-1.43 to -1.11)	0.41 (0.05 to 0.78)
35-39	-1.59 (-1.84 to -1.33)	-2.02 (-2.29 to -1.75)	NA	-1.19 (-1.44 to -0.94)	0.31 (0.2 to 0.42)
40-44	-1.44 (-1.75 to -1.12)	-2.27 (-2.41 to -2.13)	NA	-1.53 (-1.69 to -1.37)	0.11 (-0.03 to 0.25)
45-49	-1.82 (-2.01 to -1.63)	-2.77 (-2.93 to -2.6)	NA	-2.14 (-2.29 to -1.99)	-0.59 (-0.71 to -0.47)
50-54	-1.98 (-2.25 to -1.72)	-2.94 (-3.21 to -2.66)	NA	-2.54 (-2.86 to -2.22)	-0.87 (-1.32 to -0.42)
55-59	-1.96 (-2.22 to -1.71)	-3.09 (-3.3 to -2.88)	NA	-2.86 (-3.15 to -2.56)	-1.19 (-1.4 to -0.99)
60-64	-1.78 (-2.14 to -1.43)	-3.01 (-3.27 to -2.75)	NA	-3.12 (-3.4 to -2.83)	-1.39 (-1.61 to -1.17)
65-69	-1.76 (-2.1 to -1.42)	-3.05 (-3.34 to -2.75)	NA	-3.34 (-3.71 to -2.97)	-1.73 (-1.98 to -1.49)
70-74	-2 (-2.24 to -1.77)	-3.18 (-3.32 to -3.03)	NA	-3.66 (-3.91 to -3.41)	-2.16 (-2.33 to -2)
75-79	-1.69 (-1.85 to -1.54)	-2.62 (-2.84 to -2.39)	NA	-3.18 (-3.4 to -2.96)	-1.71 (-1.95 to -1.47)
80-84	-1.71 (-2.29 to -1.13)	-2.23 (-2.58 to -1.88)	NA	-2.92 (-3.45 to -2.38)	-1.53 (-1.86 to -1.2)
85-89	-1.8 (-2.23 to -1.37)	-1.98 (-2.42 to -1.53)	NA	-2.71 (-3.12 to -2.29)	-1.43 (-1.73 to -1.14)
90-94	-1.86 (-2.2 to -1.52)	-1.53 (-1.75 to -1.32)	NA	-2.3 (-2.57 to -2.02)	-1.28 (-1.49 to -1.07)
95+	-1.96 (-2.59 to -1.33)	-1.48 (-1.61 to -1.35)	NA	-2.15 (-2.28 to -2.01)	-1.34 (-1.47 to -1.22)
	High fasting plasma glucose	**Low physical activity**	**Tobacco**	**Unsafe water, sanitation, and handwashing**	
Global	-1.9 (-2.19 to -1.61)	-3.01 (-3.17 to -2.85)	-3.35 (-3.46 to -3.24)	-3.3 (-3.47 to -3.12)	
Gender					
Female	-1.78 (-2.11 to -1.44)	-2.59 (-2.73 to -2.46)	-3.76 (-3.88 to -3.65)	-3.47 (-3.64 to -3.3)	
Male	-2.04 (-2.17 to -1.92)	-3.35 (-3.53 to -3.18)	-3.24 (-3.35 to -3.13)	-3.14 (-3.22 to -3.07)	
SDI					
Low SDI	-1.37 (-1.55 to -1.19)	-2.34 (-2.52 to -2.17)	-3.13 (-3.29 to -2.97)	-2.52 (-2.62 to -2.43)	
Low-middle SDI	-1.82 (-1.97 to -1.68)	-3.07 (-3.5 to -2.64)	-3.24 (-3.45 to -3.03)	-3.21 (-3.52 to -2.9)	
Middle SDI	-3.03 (-3.28 to -2.78)	-4.03 (-4.14 to -3.92)	-3.8 (-3.93 to -3.66)	-4.66 (-4.85 to -4.48)	
High-middle SDI	-3.7 (-3.99 to -3.4)	-4.12 (-4.39 to -3.86)	-3.02 (-3.5 to -2.54)	-5.68 (-5.96 to -5.41)	
High SDI	-3.66 (-3.88 to -3.44)	-3.95 (-4.17 to -3.74)	-3.58 (-4.08 to -3.07)	-3.64 (-4.09 to -3.19)	
Region					
Australasia	-3.28 (-3.8 to -2.75)	-3.36 (-3.82 to -2.9)	-3.99 (-5.23 to -2.74)	-3.55 (-4.85 to -2.23)	
Oceania	-1.22 (-1.44 to -0.99)	-2.02 (-2.23 to -1.8)	-1.74 (-1.93 to -1.54)	-1.9 (-2.03 to -1.77)	
East Asia	-5.89 (-6.33 to -5.46)	-6.24 (-6.51 to -5.97)	-4.95 (-5.4 to -4.5)	-8.22 (-8.75 to -7.68)	
Central Asia	-0.25 (-0.99 to 0.51)	-1.6 (-1.89 to -1.3)	-2.65 (-3.17 to -2.13)	-4.91 (-5.24 to -4.57)	
South Asia	-2.2 (-2.44 to -1.95)	-3.47 (-3.87 to -3.07)	-3.65 (-3.93 to -3.38)	-3.68 (-4.04 to -3.31)	
Southeast Asia	-2.09 (-2.17 to -2.01)	-3.17 (-3.23 to -3.1)	-2.76 (-2.86 to -2.66)	-3.58 (-3.66 to -3.5)	
High-income Asia Pacific	-4.54 (-4.87 to -4.21)	-4.78 (-5.14 to -4.43)	-4.92 (-5.65 to -4.18)	-4.53 (-4.9 to -4.16)	
Eastern Europe	-0.51 (-1.28 to 0.27)	-1.08 (-1.78 to -0.37)	-0.16 (-1.64 to 1.34)	-2.33 (-3.66 to -0.98)	
Central Europe	-3.41 (-3.7 to -3.12)	-3.88 (-4.21 to -3.54)	-2.25 (-2.68 to -1.81)	-3.83 (-4.35 to -3.3)	
Western Europe	-3.9 (-4.21 to -3.59)	-4.82 (-5.36 to -4.28)	-3.66 (-4.61 to -2.7)	-3.03 (-3.94 to -2.12)	
High-income North America	-2.51 (-3.3 to -1.72)	-4.69 (-5.07 to -4.3)	-3.73 (-4.39 to -3.07)	-3.1 (-3.88 to -2.31)	
Andean Latin America	-3.78 (-4.12 to -3.44)	-4.95 (-5.62 to -4.27)	-3.68 (-4.29 to -3.07)	-4.45 (-4.98 to -3.91)	
Central Latin America	-4.83 (-5.26 to -4.4)	-5.31 (-5.62 to -5.01)	-3.93 (-4.41 to -3.45)	-4.48 (-4.86 to -4.11)	
Southern Latin America	-2.09 (-2.65 to -1.52)	-2.88 (-3.57 to -2.18)	-0.79 (-1.41 to -0.17)	-3.11 (-4.07 to -2.13)	
Tropical Latin America	-2.84 (-3.18 to -2.49)	-2.49 (-2.72 to -2.27)	-3.21 (-3.91 to -2.51)	-3.71 (-4.22 to -3.19)	
Caribbean	-2.08 (-2.5 to -1.65)	-2.27 (-2.64 to -1.9)	-2.2 (-2.74 to -1.65)	-2.34 (-2.74 to -1.94)	
North Africa and Middle East	-2.57 (-2.72 to -2.43)	-3.8 (-3.92 to -3.68)	-2.82 (-2.94 to -2.7)	-4.75 (-5 to -4.51)	
Eastern Sub-Saharan Africa	-1.85 (-1.95 to -1.76)	-2.47 (-2.59 to -2.36)	-3.25 (-3.32 to -3.18)	-2.53 (-2.64 to -2.42)	
Central Sub-Saharan Africa	-0.56 (-0.68 to -0.44)	-2.01 (-2.2 to -1.83)	-2.08 (-2.17 to -1.98)	-1.68 (-1.77 to -1.6)	
Southern Sub-Saharan Africa	1 (0.62 to 1.39)	-0.14 (-0.79 to 0.52)	-2.02 (-2.26 to -1.79)	-1.34 (-1.72 to -0.96)	
Western Sub-Saharan Africa	-0.79 (-0.9 to -0.69)	-1.8 (-1.96 to -1.64)	-2.56 (-2.67 to -2.46)	-2.05 (-2.14 to -1.96)	
Age (years)					
0-4	NA	NA	-5.96 (-6.1 to -5.82)	-4.55 (-4.8 to -4.29)	
5-9	NA	NA	-4.68 (-5.05 to -4.32)	-3.21 (-3.66 to -2.76)	
10-14	NA	NA	-3.38 (-3.87 to -2.89)	-2.1 (-2.66 to -1.54)	
15-19	NA	NA	-2.58 (-2.86 to -2.29)	-1.49 (-1.81 to -1.17)	
20-24	NA	NA	-1.97 (-2.12 to -1.81)	-1.1 (-1.31 to -0.9)	
25-29	-1.07 (-1.35 to -0.79)	-1.23 (-1.61 to -0.84)	-1.86 (-2.12 to -1.6)	-1.2 (-1.52 to -0.88)	
30-34	-1.42 (-1.61 to -1.24)	-1.48 (-1.7 to -1.27)	-3.22 (-3.48 to -2.95)	-1.43 (-1.69 to -1.16)	
35-39	-1.22 (-1.7 to -0.74)	-1.4 (-1.64 to -1.15)	-3.13 (-3.29 to -2.97)	-1.46 (-1.64 to -1.27)	
40-44	-1.49 (-1.65 to -1.33)	-1.7 (-1.86 to -1.54)	-3.19 (-3.37 to -3)	-1.37 (-1.55 to -1.18)	
45-49	-2 (-2.2 to -1.81)	-2.38 (-2.54 to -2.23)	-3.43 (-3.57 to -3.3)	-1.88 (-2.06 to -1.69)	
50-54	-2.07 (-2.48 to -1.65)	-2.51 (-2.86 to -2.16)	-3.5 (-3.84 to -3.15)	-2.03 (-2.23 to -1.82)	
55-59	-2.17 (-2.55 to -1.79)	-3 (-3.29 to -2.71)	-3.32 (-3.53 to -3.11)	-2.07 (-2.25 to -1.89)	
60-64	-1.92 (-2.16 to -1.67)	-3.45 (-3.78 to -3.12)	-3.1 (-3.45 to -2.76)	-1.99 (-2.3 to -1.67)	
65-69	-1.73 (-2.3 to -1.17)	-3.53 (-3.95 to -3.1)	-3.06 (-3.38 to -2.75)	-2.02 (-2.46 to -1.58)	
70-74	-2.12 (-2.38 to -1.87)	-3.51 (-3.66 to -3.36)	-3.08 (-3.31 to -2.85)	-2.3 (-2.56 to -2.03)	
75-79	-1.82 (-2.02 to -1.62)	-3.11 (-3.36 to -2.86)	-2.64 (-2.88 to -2.39)	-1.82 (-2.06 to -1.57)	
80-84	-1.91 (-2.32 to -1.49)	-2.92 (-3.38 to -2.46)	-2.42 (-2.7 to -2.14)	-1.84 (-2.12 to -1.55)	
85-89	-1.61 (-1.93 to -1.29)	-2.58 (-3.02 to -2.13)	-2.15 (-2.67 to -1.62)	-2.15 (-2.79 to -1.51)	
90-94	-1.38 (-1.73 to -1.03)	-2.26 (-2.6 to -1.92)	-2.04 (-2.43 to -1.66)	-2.28 (-2.92 to -1.63)	
95+	-1.42 (-1.73 to -1.1)	-2.11 (-2.28 to -1.95)	-2.08 (-2.65 to -1.5)	-2.31 (-2.88 to -1.73)	

Table 2. Annual average percentage change (AAPC) in age-standardized disability-adjusted life years (DALY) rates of respiratory infections and tuberculosis attributable to 9 risk factors, by age, gender, socio-demographic index (SDI), and regions, 1990–2021 (95% CI).

Characteristics	Air pollution	Alcohol use	Child and maternal malnutrition	Dietary risks	High body-mass index
Global	-4.01 (-4.24 to -3.78)	-2.4 (-2.47 to -2.33)	-4.46 (-4.54 to -4.39)	-2.45 (-2.54 to -2.36)	-0.69 (-0.81 to -0.58)
Gender					
Female	-4.24 (-4.49 to -3.99)	-2.38 (-2.47 to -2.29)	-4.67 (-4.89 to -4.46)	-2.12 (-2.27 to -1.97)	-0.67 (-0.83 to -0.52)
Male	-3.81 (-3.87 to -3.74)	-2.42 (-2.5 to -2.35)	-4.31 (-4.37 to -4.24)	-2.66 (-2.75 to -2.57)	-0.76 (-0.85 to -0.66)
SDI					
Low SDI	-3.6 (-3.67 to -3.52)	-2.5 (-2.63 to -2.37)	-4.64 (-4.75 to -4.53)	-2.32 (-2.42 to -2.23)	-0.53 (-0.65 to -0.42)
Low-middle SDI	-4.13 (-4.4 to -3.87)	-2.29 (-2.52 to -2.06)	-4.75 (-5 to -4.5)	-2.62 (-2.74 to -2.49)	-0.62 (-0.76 to -0.48)
Middle SDI	-5.62 (-5.92 to -5.32)	-3.24 (-3.39 to -3.09)	-6.25 (-6.44 to -6.06)	-3.28 (-3.37 to -3.19)	-1.55 (-1.83 to -1.28)
High-middle SDI	-6.39 (-6.76 to -6.02)	-4.3 (-4.69 to -3.91)	-8.32 (-8.58 to -8.06)	-3.81 (-4.17 to -3.44)	-2.13 (-2.45 to -1.81)
High SDI	-3.94 (-4.52 to -3.36)	-5.94 (-6.06 to -5.81)	-6.58 (-6.94 to -6.21)	-3.68 (-3.93 to -3.43)	-2.94 (-3.06 to -2.83)
Region					
Australasia	-2.4 (-3.78 to -1)	-4.06 (-4.47 to -3.64)	-6.08 (-7.24 to -4.89)	-3.34 (-3.81 to -2.87)	-3.1 (-3.51 to -2.7)
Oceania	-2.11 (-2.27 to -1.94)	-2.15 (-2.41 to -1.88)	-2.06 (-2.4 to -1.73)	-1.86 (-2.05 to -1.68)	-1.28 (-1.43 to -1.12)
East Asia	-8.12 (-8.4 to -7.84)	-5.52 (-5.76 to -5.28)	-9.37 (-9.66 to -9.08)	-5.07 (-5.24 to -4.89)	-3.27 (-3.55 to -2.99)
Central Asia	-4.37 (-4.78 to -3.95)	-2.81 (-3.38 to -2.25)	-5.25 (-5.53 to -4.97)	-1.33 (-1.82 to -0.84)	-1.33 (-1.64 to -1.02)
South Asia	-4.11 (-4.41 to -3.81)	-2.82 (-3.14 to -2.5)	-4.47 (-4.79 to -4.15)	-2.91 (-3.02 to -2.8)	-0.84 (-1.11 to -0.57)
Southeast Asia	-4.9 (-5 to -4.79)	-1.53 (-1.66 to -1.41)	-5.73 (-5.82 to -5.63)	-3.05 (-3.12 to -2.98)	-1.12 (-1.19 to -1.04)
High-income Asia Pacific	-3.63 (-4.04 to -3.23)	-7.03 (-7.49 to -6.57)	-7.11 (-7.71 to -6.51)	-5.35 (-5.53 to -5.17)	-4.97 (-5.21 to -4.73)
Eastern Europe	-4.01 (-5.12 to -2.88)	-1.75 (-2.88 to -0.6)	-6.24 (-6.97 to -5.5)	-3.3 (-4 to -2.6)	0.04 (-0.82 to 0.9)
Central Europe	-4.83 (-5.31 to -4.35)	-4.52 (-5.13 to -3.91)	-7.17 (-7.93 to -6.4)	-2.61 (-3.36 to -1.86)	-3.51 (-4.11 to -2.89)
Western Europe	-4.58 (-5.51 to -3.63)	-5.64 (-5.88 to -5.39)	-6.12 (-6.92 to -5.32)	-4.81 (-5.19 to -4.44)	-4.55 (-4.93 to -4.18)
High-income North America	-5.26 (-5.81 to -4.71)	-4.35 (-4.74 to -3.95)	-4.53 (-5.47 to -3.59)	-3.43 (-3.85 to -3.01)	-3.98 (-4.35 to -3.61)
Andean Latin America	-5.77 (-7.01 to -4.52)	-5.68 (-6.09 to -5.27)	-7.81 (-8.42 to -7.2)	-4.59 (-5.04 to -4.14)	-4.05 (-4.52 to -3.58)
Central Latin America	-4.99 (-5.49 to -4.49)	-4.82 (-5.15 to -4.49)	-5.64 (-6.16 to -5.12)	-4.61 (-4.9 to -4.33)	-3.92 (-4.2 to -3.64)
Southern Latin America	-2.33 (-3.34 to -1.31)	-4.63 (-5.35 to -3.9)	-6.59 (-7.94 to -5.23)	-2.49 (-3.4 to -1.57)	-2.81 (-3.63 to -1.98)
Tropical Latin America	-5.52 (-6 to -5.03)	-3.37 (-3.6 to -3.13)	-8.85 (-9.25 to -8.44)	-1.56 (-1.79 to -1.32)	-1.51 (-1.76 to -1.26)
Caribbean	-2.44 (-2.71 to -2.17)	-2.42 (-2.71 to -2.13)	-3.21 (-3.48 to -2.94)	-1.67 (-2.13 to -1.21)	-0.31 (-0.65 to 0.04)
North Africa and Middle East	-4.71 (-4.87 to -4.55)	-5.94 (-6.07 to -5.81)	-6.47 (-6.7 to -6.24)	-3.23 (-3.32 to -3.15)	-2.87 (-2.96 to -2.78)
Eastern Sub-Saharan Africa	-3.81 (-4.05 to -3.58)	-2.79 (-2.83 to -2.75)	-5.61 (-5.88 to -5.34)	-2.61 (-2.69 to -2.54)	-0.69 (-0.81 to -0.57)
Central Sub-Saharan Africa	-3.07 (-3.15 to -3)	-1.85 (-2.01 to -1.69)	-5.99 (-6.13 to -5.85)	-1.73 (-1.93 to -1.53)	0.4 (0.27 to 0.54)
Southern Sub-Saharan Africa	-2.01 (-2.3 to -1.72)	-1.38 (-1.92 to -0.83)	-3.18 (-3.59 to -2.77)	0.1 (-0.36 to 0.56)	0.66 (-0.06 to 1.38)
Western Sub-Saharan Africa	-3.17 (-3.31 to -3.04)	-2.54 (-2.71 to -2.37)	-3.99 (-4.21 to -3.76)	-1.69 (-1.85 to -1.53)	-0.55 (-0.7 to -0.4)
Age (years)					
0-4	-4.76 (-5 to -4.52)	NA	-4.65 (-4.98 to -4.31)	NA	NA
5-9	-3.61 (-4.14 to -3.07)	NA	NA	NA	NA
10-14	-2.42 (-3.04 to -1.8)	NA	NA	NA	NA
15-19	-1.86 (-2.08 to -1.64)	-1.45 (-1.64 to -1.26)	NA	NA	NA
20-24	-1.44 (-1.64 to -1.24)	-1.5 (-1.69 to -1.31)	NA	NA	NA
25-29	-1.35 (-1.59 to -1.11)	-1.53 (-1.82 to -1.24)	NA	-0.86 (-1.21 to -0.5)	1.1 (0.91 to 1.3)
30-34	-1.55 (-1.95 to -1.16)	-1.91 (-2.08 to -1.74)	NA	-1.15 (-1.3 to -1.01)	0.51 (0.16 to 0.86)
35-39	-1.58 (-1.83 to -1.32)	-1.96 (-2.21 to -1.7)	NA	-1.12 (-1.35 to -0.88)	0.38 (0.28 to 0.49)
40-44	-1.43 (-1.75 to -1.12)	-2.21 (-2.35 to -2.08)	NA	-1.46 (-1.62 to -1.31)	0.17 (0.04 to 0.3)
45-49	-1.81 (-2.01 to -1.62)	-2.7 (-2.85 to -2.54)	NA	-2.06 (-2.21 to -1.91)	-0.52 (-0.64 to -0.41)
50-54	-1.98 (-2.25 to -1.71)	-2.87 (-3.13 to -2.6)	NA	-2.47 (-2.78 to -2.16)	-0.81 (-1.24 to -0.37)
55-59	-1.96 (-2.22 to -1.7)	-3.02 (-3.22 to -2.82)	NA	-2.78 (-3.06 to -2.5)	-1.1 (-1.29 to -0.91)
60-64	-1.78 (-2.13 to -1.43)	-2.94 (-3.19 to -2.68)	NA	-3.03 (-3.3 to -2.76)	-1.32 (-1.53 to -1.1)
65-69	-1.76 (-2.1 to -1.43)	-2.91 (-3.18 to -2.63)	NA	-3.2 (-3.55 to -2.86)	-1.59 (-1.82 to -1.37)
70-74	-2 (-2.23 to -1.76)	-3.05 (-3.17 to -2.93)	NA	-3.49 (-3.72 to -3.26)	-1.97 (-2.14 to -1.8)
75-79	-1.69 (-1.84 to -1.54)	-2.48 (-2.69 to -2.27)	NA	-3.05 (-3.24 to -2.85)	-1.54 (-1.72 to -1.36)
80-84	-1.69 (-1.98 to -1.4)	-2.13 (-2.47 to -1.78)	NA	-2.82 (-3.33 to -2.3)	-1.41 (-1.78 to -1.05)
85-89	-1.82 (-2.27 to -1.37)	-1.92 (-2.33 to -1.5)	NA	-2.65 (-3.03 to -2.27)	-1.35 (-1.63 to -1.08)
90-94	-1.86 (-2.2 to -1.52)	-1.53 (-1.73 to -1.32)	NA	-2.3 (-2.55 to -2.05)	-1.29 (-1.5 to -1.09)
95+	-1.98 (-2.63 to -1.33)	-1.54 (-1.66 to -1.41)	NA	-2.19 (-2.32 to -2.07)	-1.33 (-1.44 to -1.21)

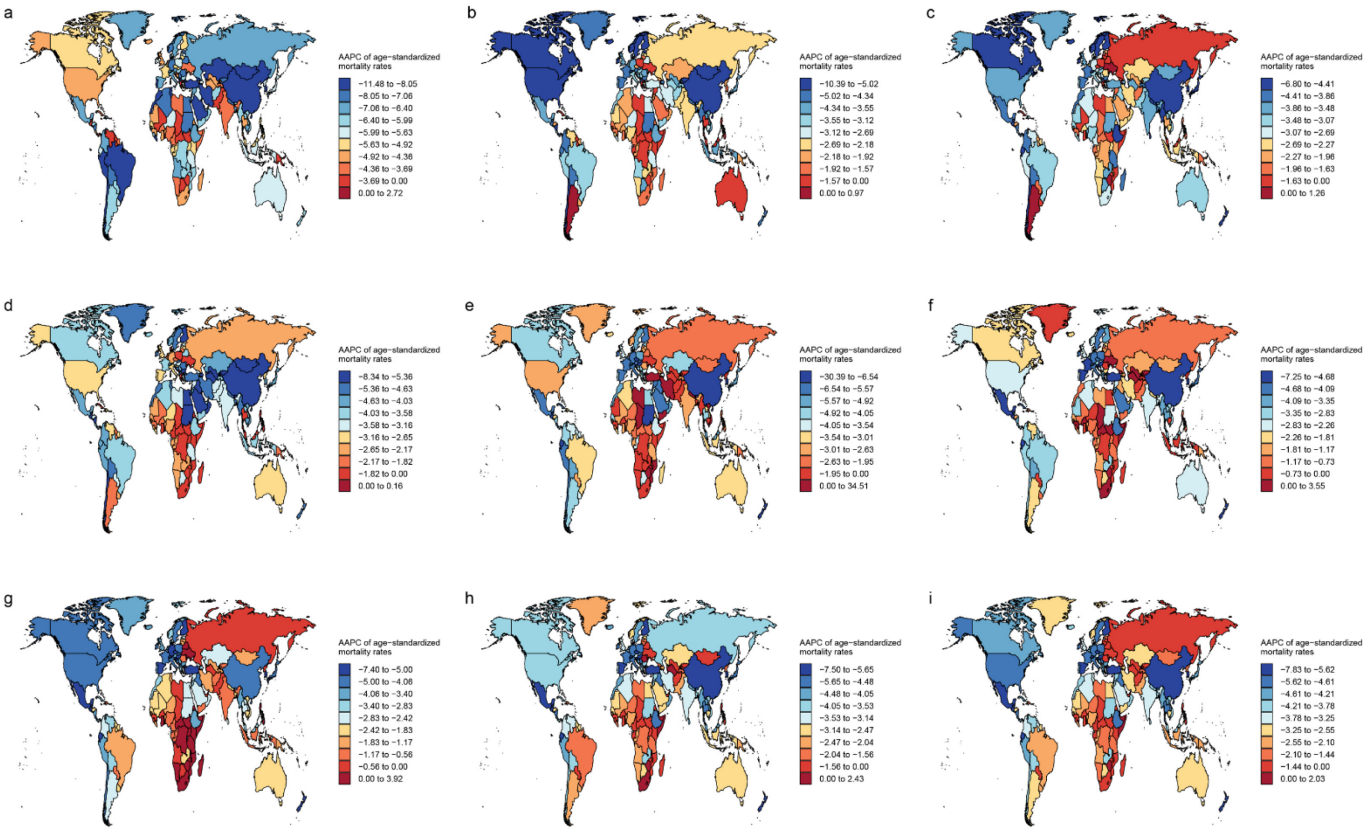
	High fasting plasma glucose	Low physical activity	Tobacco	Unsafe water, sanitation, and handwashing
Global	-1.81 (-2.05 to -1.56)	-2.79 (-2.91 to -2.67)	-4.07 (-4.16 to -3.97)	-3.89 (-4.11 to -3.68)
Gender				
Female	-1.76 (-2.09 to -1.43)	-2.41 (-2.52 to -2.3)	-4.81 (-4.91 to -4.7)	-4.11 (-4.3 to -3.93)
Male	-1.9 (-2.16 to -1.64)	-3.1 (-3.22 to -2.99)	-3.77 (-3.86 to -3.67)	-3.66 (-3.84 to -3.48)
SDI				
Low SDI	-1.48 (-1.59 to -1.37)	-2.37 (-2.45 to -2.28)	-3.75 (-3.88 to -3.62)	-3.62 (-3.72 to -3.52)
Low-middle SDI	-1.85 (-2.07 to -1.64)	-3.04 (-3.36 to -2.72)	-3.94 (-4.03 to -3.84)	-4.44 (-4.65 to -4.23)
Middle SDI	-2.78 (-2.96 to -2.59)	-3.66 (-3.76 to -3.56)	-4.76 (-4.87 to -4.65)	-5.87 (-6.01 to -5.73)

High-middle SDI	-3.33 (-3.65 to -3)	-3.55 (-3.82 to -3.28)	-4.2 (-4.49 to -3.9)	-8.06 (-8.22 to -7.9)
High SDI	-3.84 (-3.99 to -3.69)	-3.99 (-4.13 to -3.84)	-3.71 (-4.2 to -3.22)	-4.67 (-5.01 to -4.33)
Region				
Australasia	-3.66 (-4.15 to -3.16)	-3.14 (-3.56 to -2.72)	-4.24 (-5.35 to -3.11)	-4.2 (-5.4 to -2.98)
Oceania	-1.08 (-1.29 to -0.88)	-2 (-2.14 to -1.86)	-1.74 (-1.91 to -1.57)	-2.1 (-2.27 to -1.93)
East Asia	-5.29 (-5.77 to -4.81)	-5.52 (-5.74 to -5.29)	-6.38 (-6.69 to -6.07)	-10.27 (-10.56 to -9.98)
Central Asia	-0.41 (-1.11 to 0.29)	-1.61 (-1.94 to -1.27)	-3.72 (-4 to -3.45)	-5.62 (-6.03 to -5.2)
South Asia	-2.21 (-2.41 to -2.02)	-3.46 (-3.72 to -3.2)	-4.29 (-4.42 to -4.16)	-4.91 (-5.12 to -4.71)
Southeast Asia	-1.93 (-2 to -1.85)	-2.92 (-3 to -2.84)	-3.55 (-3.6 to -3.49)	-5.48 (-5.55 to -5.41)
High-income Asia Pacific	-5.27 (-5.81 to -4.72)	-5.48 (-5.71 to -5.26)	-5.16 (-6.06 to -4.25)	-4.96 (-5.32 to -4.59)
Eastern Europe	-0.36 (-1.13 to 0.42)	-0.82 (-1.59 to -0.06)	-0.89 (-2.37 to 0.62)	-3.74 (-4.35 to -3.13)
Central Europe	-3.21 (-4.02 to -2.4)	-3.48 (-4.08 to -2.87)	-3.27 (-3.66 to -2.87)	-5.83 (-6.35 to -5.31)
Western Europe	-4.14 (-4.59 to -3.69)	-4.95 (-5.35 to -4.54)	-3.71 (-4.6 to -2.81)	-3.46 (-4.33 to -2.58)
High-income North America	-2.39 (-3.01 to -1.78)	-4.24 (-4.57 to -3.91)	-3.48 (-4.36 to -2.59)	-3.01 (-3.81 to -2.2)
Andean Latin America	-3.94 (-4.26 to -3.63)	-4.81 (-5.41 to -4.2)	-4.78 (-5.11 to -4.46)	-6.18 (-6.68 to -5.68)
Central Latin America	-4.59 (-4.86 to -4.31)	-4.8 (-5.07 to -4.52)	-4.47 (-4.94 to -4.01)	-5.35 (-5.7 to -5)
Southern Latin America	-2.25 (-3.07 to -1.42)	-2.86 (-3.45 to -2.26)	-1.66 (-2.39 to -0.92)	-4.15 (-4.81 to -3.49)
Tropical Latin America	-2.73 (-3.03 to -2.43)	-2.23 (-2.48 to -1.98)	-4.45 (-4.92 to -3.98)	-5.91 (-6.29 to -5.53)
Caribbean	-1.9 (-2.29 to -1.52)	-1.85 (-2.23 to -1.47)	-2.8 (-3.17 to -2.42)	-2.7 (-2.96 to -2.43)
North Africa and Middle East	-2.45 (-2.58 to -2.32)	-3.41 (-3.53 to -3.29)	-4.19 (-4.26 to -4.11)	-6.01 (6.19 to -5.84)
Eastern Sub-Saharan Africa	-1.93 (-1.99 to -1.87)	-2.6 (-2.68 to -2.52)	-3.65 (-3.78 to -3.53)	-3.75 (-3.98 to -3.52)
Central Sub-Saharan Africa	-0.5 (-0.64 to -0.37)	-1.95 (-2.15 to -1.75)	-2.6 (-2.68 to -2.51)	-3.17 (-3.27 to -3.08)
Southern Sub-Saharan Africa	1.04 (0.66 to 1.42)	-0.3 (-0.88 to 0.29)	-2.35 (-2.67 to -2.02)	-2.14 (-2.44 to -1.85)
Western Sub-Saharan Africa	-0.83 (-0.9 to -0.75)	-1.8 (-1.92 to -1.69)	-3.25 (-3.37 to -3.13)	-3.09 (-3.22 to -2.96)
Age (years)				
0-4	NA	NA	-5.93 (-6.07 to -5.8)	-4.55 (-4.8 to -4.29)
5-9	NA	NA	-4.35 (-4.69 to -4.02)	-3.21 (-3.65 to -2.76)
10-14	NA	NA	-3.09 (-3.57 to -2.62)	-2.1 (-2.65 to -1.54)
15-19	NA	NA	-2.56 (-2.79 to -2.34)	-1.49 (-1.8 to -1.17)
20-24	NA	NA	-1.95 (-2.1 to -1.8)	-1.1 (-1.31 to -0.9)
25-29	-0.91 (-1.15 to -0.66)	-0.98 (-1.16 to -0.8)	-1.84 (-2.1 to -1.59)	-1.2 (-1.52 to -0.87)
30-34	-1.3 (-1.47 to -1.13)	-1.36 (-1.56 to -1.15)	-3.17 (-3.43 to -2.91)	-1.42 (-1.69 to -1.16)
35-39	-1.15 (-1.6 to -0.7)	-1.32 (-1.54 to -1.09)	-3.11 (-3.27 to -2.95)	-1.45 (-1.64 to -1.27)
40-44	-1.43 (-1.57 to -1.28)	-1.63 (-1.78 to -1.48)	-3.1 (-3.32 to -2.89)	-1.37 (-1.56 to -1.18)
45-49	-1.93 (-2.11 to -1.74)	-2.31 (-2.46 to -2.16)	-3.41 (-3.54 to -3.29)	-1.87 (-2.06 to -1.68)
50-54	-2 (-2.39 to -1.61)	-2.45 (-2.78 to -2.12)	-3.47 (-3.8 to -3.14)	-2.02 (-2.23 to -1.82)
55-59	-2.09 (-2.44 to -1.73)	-2.92 (-3.18 to -2.66)	-3.27 (-3.52 to -3.02)	-2.07 (-2.24 to -1.89)
60-64	-1.81 (-2.05 to -1.58)	-3.36 (-3.68 to -3.05)	-3.09 (-3.43 to -2.75)	-1.98 (-2.29 to -1.67)
65-69	-1.62 (-2.15 to -1.09)	-3.39 (-3.78 to -3)	-3.03 (-3.34 to -2.72)	-2.02 (-2.45 to -1.59)
70-74	-1.98 (-2.22 to -1.74)	-3.36 (-3.5 to -3.23)	-3.05 (-3.28 to -2.82)	-2.29 (-2.56 to -2.03)
75-79	-1.7 (-1.89 to -1.51)	-2.98 (-3.2 to -2.76)	-2.62 (-2.85 to -2.38)	-1.82 (-2.06 to -1.58)
80-84	-1.82 (-2.21 to -1.43)	-2.83 (-3.25 to -2.39)	-2.42 (-2.7 to -2.15)	-1.84 (-2.11 to -1.56)
85-89	-1.56 (-1.86 to -1.27)	-2.53 (-2.94 to -2.11)	-2.16 (-2.66 to -1.66)	-2.16 (-2.79 to -1.53)
90-94	-1.33 (-1.69 to -0.98)	-2.25 (-2.56 to -1.94)	-2.05 (-2.42 to -1.67)	-2.28 (-2.92 to -1.64)
95+	-1.4 (-1.74 to -1.05)	-2.16 (-2.32 to -2)	-2.11 (-2.69 to -1.53)	-2.31 (-2.91 to -1.71)

Similarly, Lesotho experienced the highest increases in ASMR due to high BMI (3.92, 95% CI: 3.58 to 4.26), high FPG (3.55, 95% CI: 3.24 to 3.86), low physical activity (2.03, 95% CI: 1.53 to 2.54), and tobacco use (1.26, 95% CI: 0.94 to 1.58). The most substantial reductions were observed in Hungary (−7.4, 95% CI: −7.99 to −6.8 for high BMI; −7.83, 95% CI: −8.45 to −7.2 for low physical activity), Singapore (− 7.25, 95% CI: − 8.11 to − 6.38 for high FPG), and Finland (− 6.8, 95% CI: − 8.01 to − 5.56 for tobacco). Finally, unsafe water, sanitation, and handwashing contributed to a slight increase in ASMR in Lesotho (0.16, 95% CI: − 0.09 to 0.42), while China achieved the largest decline (− 8.34, 95% CI: − 8.9 to − 7.78).

Similar geographic variations were noted in the AAPC of ASDR across different risk factors. Most countries exhibited a declining trend in ASDR AAPC. Tokelau exhibited the largest upward trend in ASDR due to air pollution (AAPC: 0.61, 95% CI: − 0.85 to 2.09), while Finland showed the steepest decline (− 9.89, 95% CI: − 12.54 to − 7.16). Iran recorded the highest increase for alcohol use (33.59, 95% CI: 30.44 to 36.82), whereas Sudan achieved the largest reduction (− 29.36, 95% CI: − 31.66 to − 26.98). Child and maternal malnutrition-related ASDR increased most in Tokelau (2.71, 95% CI: 0.70 to 4.77), but decreased sharply in Iran (− 11.48, 95% CI: − 12.11 to − 10.85). Dietary risks drove the largest ASDR rise in Lesotho (2.68, 95% CI: 2.23 to 3.14), while the Maldives experienced the greatest decline (− 7.48, 95% CI: − 7.68

Figure 2. Average annual percentage change (AAPC) of age-standardized mortality rates (ASMR) in respiratory infections and tuberculosis across 204 countries and territories, 1990–2021: (a) child and maternal malnutrition; (b) air pollution; (c) tobacco; (d) unsafe water, sanitation, and handwashing; (e) alcohol use; (f) high fasting plasma glucose; (g) high body-mass index; (h) dietary risks; (i) low physical activity.



to − 7.27). Similarly, Lesotho had the highest increases in ASDR due to high BMI (4.15, 95% CI: 3.80 to 4.50), high FPG (3.66, 95% CI: 3.36 to 3.97), low physical activity (2.16, 95% CI: 1.66 to 2.67), and tobacco use (1.45, 95% CI: 0.94 to 1.97). The most substantial reductions were observed in Hungary (− 6.98, 95% CI: − 7.71 to − 6.24 for high BMI), Singapore (− 7.24, 95% CI: − 7.72 to − 6.76 for high FPG), the Maldives (− 7.47, 95% CI: − 7.69 to − 7.25 for low physical activity), and China (− 6.51, 95% CI: − 6.75 to − 6.26 for tobacco). Finally, unsafe water, sanitation, and handwashing contributed to a slight increase in ASDR in Niue (0.61, 95% CI: 0.47 to 0.74), while China achieved the largest decline (− 10.37, 95% CI: − 10.66 to − 10.07).

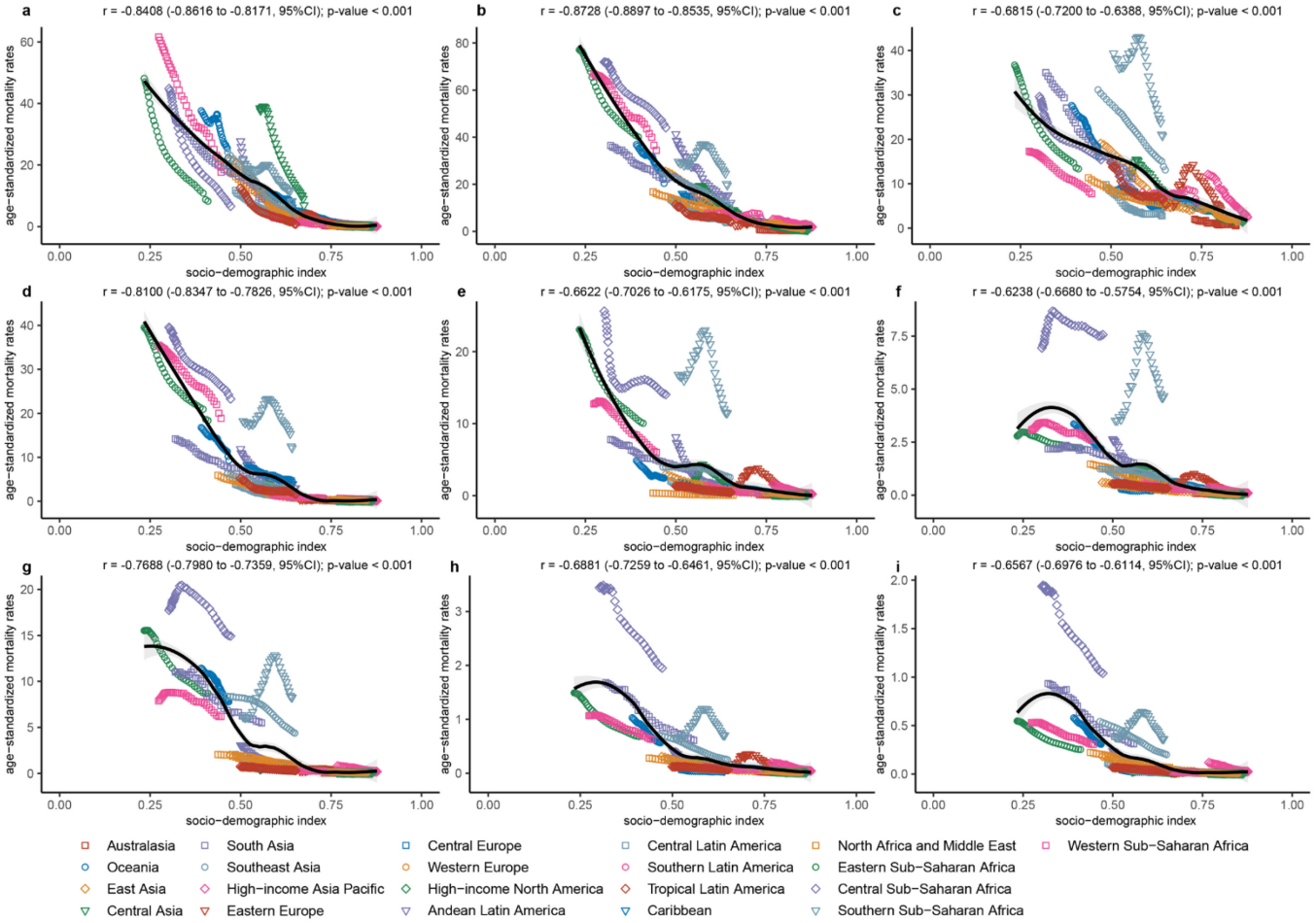
Correlation of respiratory infections and tuberculosis burden attributable to risk factors with SDI across 21 GBD regions

The analysis revealed a strong inverse correlation between SDI and both ASMR and ASDR for respiratory infections and tuberculosis across 21 GBD regions from 1990 to 2021. As SDI increased, ASMR and ASDR exhibited a consistent decline in most regions (Figure 3). However, risk-specific heterogeneity was evident: air pollution showed the strongest inverse correlation with SDI for both ASMR (r = − 0.873, 95% CI: − 0.890 to − 0.854) and ASDR (r = − 0.888, 95% CI: − 0.903 to − 0.871), whereas high FPG exhibited the weakest correlation (ASMR: r = − 0.624, 95% CI: − 0.668 to − 0.575; ASDR: r = − 0.595, 95% CI: − 0.642 to − 0.544). Notably, metabolic and behavioral risks—including FPG, dietary risks, and low physical activity—demonstrated complex patterns. While higher SDI was generally associated with elevated ASMR and ASDR for these risks, regions with SDI < 0.3 (e.g., Eastern Sub-Saharan Africa) exhibited a paradoxical decline in ASMR and ASDR with rising SDI (Figure 3).

Region-specific proportions of respiratory infections and tuberculosis burden attributable to risk factors

Globally, between 1990 and 2021, 92% of deaths (83% in 2021) and 96% of DALYs (89% in 2021) from respiratory infections and tuberculosis were attributable to 4 major risk factors: child and maternal malnutrition;

Figure 3. Association between age-standardized mortality rates (ASMR) and sociodemographic index (SDI) for respiratory infections and tuberculosis attributable to risk factors, across 21 GBD regions, 1990–2021: (a) child and maternal malnutrition; (b) air pollution; (c) tobacco use; (d) unsafe water, sanitation, and handwashing; (e) alcohol use; (f) high fasting plasma glucose; (g) high body-mass index; (h) dietary risks; (i) low physical activity.



air pollution; tobacco use; and unsafe water, sanitation, and handwashing (Figure 4).

In 1990, risk factor profiles for deaths from respiratory infections and tuberculosis diverged markedly by SDI. In high SDI regions—including Australasia, high-income Asia Pacific, Western Europe, and high-income North America—tobacco use accounted for 51% of deaths, representing the leading risk factor. In contrast, child and maternal malnutrition dominated in lower SDI regions, with the highest burden observed in low SDI regions (43% of deaths). This burden decreased progressively in higher SDI regions: low-middle SDI regions attributed 39% of deaths to malnutrition, followed by middle SDI regions (37%) and high-middle SDI regions (29%) ($p < 0.001$ for trend across SDI categories) (Figure 4). A similar gradient was observed for DALYs in 1990. In high SDI regions, tobacco use contributed to 45% of DALYs, whereas child and maternal malnutrition remained the primary driver in lower SDI regions. Low SDI regions exhibited the highest malnutrition-related DALY burden (49%), followed by low-middle SDI regions (47%), middle SDI regions (47%), and high-middle SDI regions (43%).

By 2021, tobacco use had surpassed child and maternal malnutrition as the leading risk factor for deaths in middle and high-middle SDI regions, accounting for 32% of deaths in middle SDI regions and 48% in high-middle SDI regions. Similar transitions were observed in East Asia, Eastern Europe, Central Europe, Southern Latin America, and Tropical Latin America (Figure 4). Concurrently, metabolic and behavioral risks—including high FPG, elevated body-mass index, dietary risks, and physical inactivity—demonstrated a marked global increase in attributable mortality compared to 1990. In low SDI regions, the proportion of deaths attributable to these risks rose from 5% in 1990 to 27% in 2021, while in low-middle SDI

Figure 4. Proportion of deaths attributable to risk factors for respiratory infections and tuberculosis, by region, in 1990 (a) and 2021 (b).

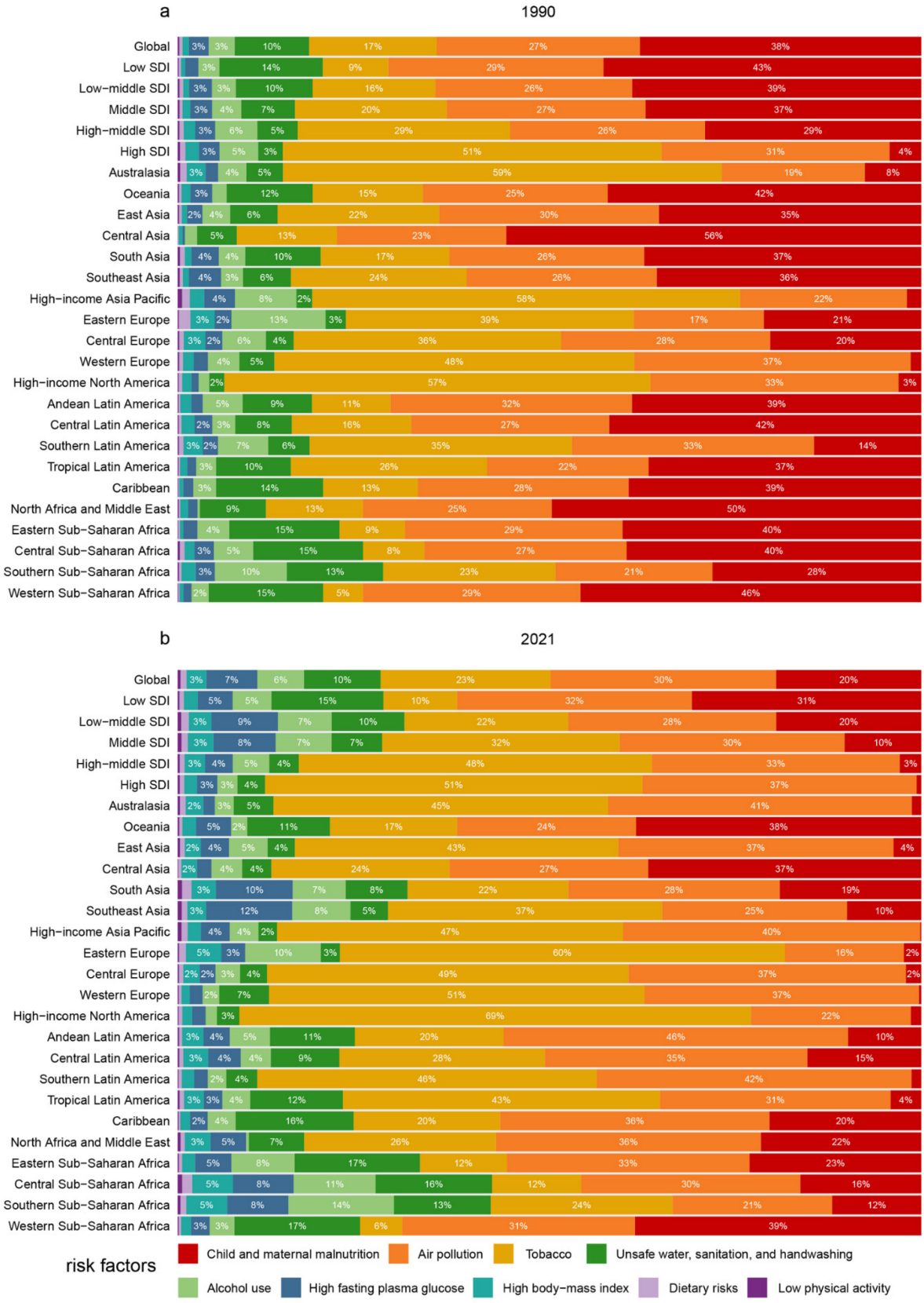
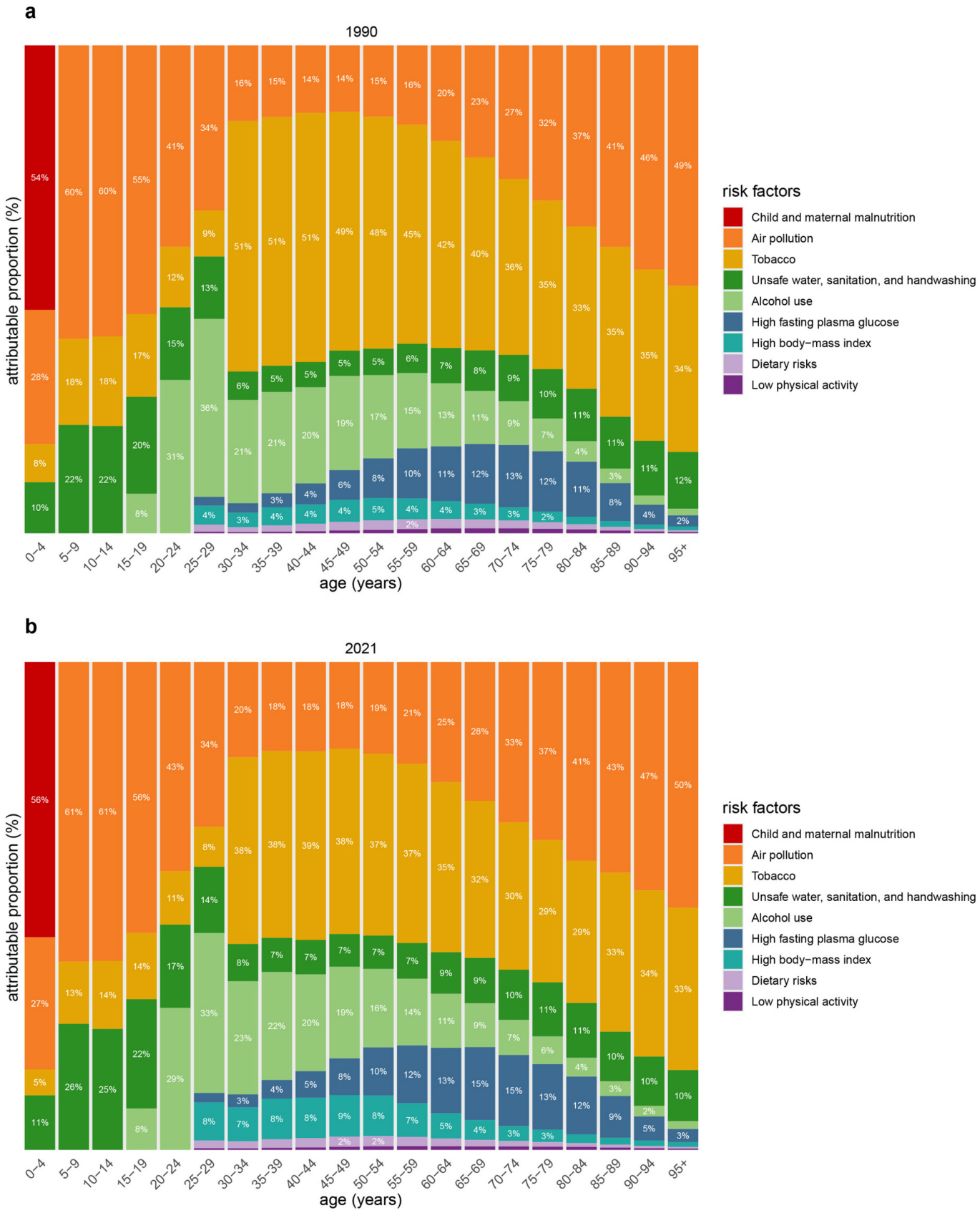


Figure 5. Proportion of deaths attributable to risk factors for respiratory infections and tuberculosis globally, by age disparity, in 1990 (a) and 2021 (b).



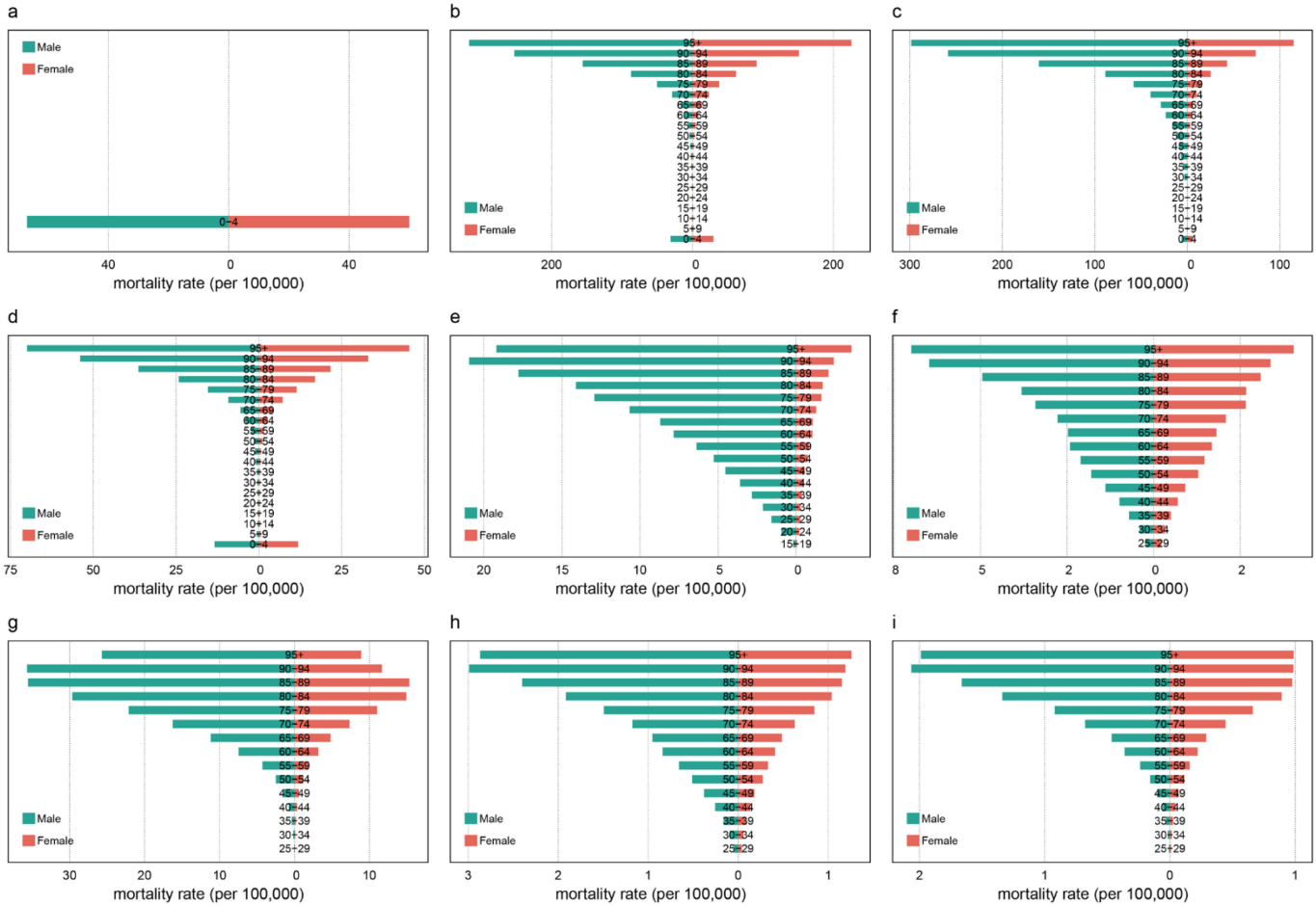
regions, the increase was from 9% to 20% over the same period. Southern, Central, and Eastern Sub-Saharan Africa exhibited the most pronounced rises in metabolic and behavioral risk-related deaths, underscoring an accelerating epidemiological transition in these regions (Figure 4). Parallel trends were observed for DALYs. By 2021, tobacco use accounted for 26% of DALYs in middle SDI regions and 46% in high-middle SDI regions, surpassing malnutrition as the leading contributor.

Age-specific proportions of respiratory infections and tuberculosis burden attributable to risk factors

In 1990, child and maternal malnutrition primarily affected deaths in children under 5 years of age. Metabolic and behavioral risks—including high FPG, high BMI, dietary risks, and physical inactivity—began to contribute significantly to mortality from 25 years onwards. By 30 years of age, tobacco use emerged as the leading risk factor for deaths, accounting for 51% of cases, while air pollution decreased to 16%, becoming the secondary risk factor. With increasing age, the contribution of alcohol use and tobacco use to deaths declined annually, whereas the proportion of deaths attributable to air pollution and unsafe water, sanitation, and handwashing increased steadily (Figure 5).

Similar trends were observed by 2021, though the proportion of deaths due to tobacco use decreased among individuals aged 30–59 years compared to 1990. Specifically, tobacco-related deaths declined from 51% to 38% in the 30–34 years age group, from 51% to 38% in the 35–39 years age group, from 51% to 39% in the 40–44 years age group, from 49% to 38% in the 45–49 years age group, from 48% to 37% in the 50–54 years age group, and from 45% to 35% in the 55–59 years age group (Figure 5). Parallel trends were observed for DALYs, with tobacco use showing a consistent decline in attributable burden across the same age groups.

Figure 6. Age-specific mortality rates for respiratory infections and tuberculosis attributable to risk factors, by gender, in 2021: (a) child and maternal malnutrition; (b) air pollution; (c) tobacco use; (d) unsafe water, sanitation, and handwashing; (e) alcohol use; (f) high fasting plasma glucose; (g) high body-mass index; (h) dietary risks; (i) low physical activity.



Gender disparities in the burden of respiratory infections and tuberculosis burden attributable to risk factors

In 2021, age- and gender-specific mortality patterns for respiratory infections and tuberculosis revealed pronounced disparities, with males exhibiting higher mortality risks than females across nearly all risk factors, and rates increasing progressively with age until 95 years (Figure 6). No significant gender-based difference was observed for malnutrition-related mortality (Figure 6A). Air pollution predominantly affected individuals aged ≥ 70 years, with higher mortality in males (62.83 per 100,000, 95% UI: 8.32–105.31) than females (49.59 per 100,000, 95% UI: 6.91–83.73) (Figure 6B). Unsafe water, sanitation, and handwashing led to higher mortality in males than females, with rates increasing from 5–9 years onward in both genders (Figure 6D). Tobacco and alcohol use significantly impacted males across nearly all age groups, with ASMR for tobacco 3.6-fold higher in males (9.94 per 100,000, 95% UI: 6.90–12.84) than females (2.73 per 100,000, 95% UI: 1.33–4.24) ($p < 0.001$), and alcohol-related mortality 7.6-fold higher in males (2.89 per 100,000, 95% UI: −1.94 to 10.39) than females (0.38 per 100,000, 95% UI: −0.15 to 1.73) (Figure 6C, E). Metabolic and behavioral risks—including high FPG, elevated BMI, dietary risks, and physical inactivity—also showed higher mortality in males than females across nearly all age groups (Figure 6F–I). Additionally, DALY rates were highest in children under 5 years, primarily due to air pollution and unsafe water, sanitation, and handwashing, with males bearing a higher burden than females.

Discussion

Previous studies have predominantly focused on aggregated estimates of respiratory infections and tuberculosis burden, often overlooking critical heterogeneities across age, gender, and socioeconomic strata [15,27,28]. While the role of traditional risks, such as malnutrition and air pollution are well-documented [29–31], the evolving contribution of metabolic and behavioral factors in the context of global epidemiological transitions remains underexplored. Detailed analyses stratified by age, gender, SDI, and geographic region were conducted to comprehensively assess the burden of respiratory infections and tuberculosis. These stratifications enabled the identification of disparities in risk factor impacts across populations and over time, providing critical insights for precision public health interventions.

Globally, the ASMR for respiratory infections and tuberculosis attributable to traditional risks declined significantly between 1990 and 2021. Specifically, AAPC was − 4.46% for malnutrition and − 3.35% for tobacco use. These reductions align with improvements in sanitation, and tobacco control policies [4–6,32–34]. However, metabolic risks—high BMI and FPG—exhibited paradoxical trends. Although their ASMR and ASDR declined (28.7% and 44.5%, respectively), absolute deaths and DALYs rose sharply, reflecting population growth and aging. Traditional risks like malnutrition and tobacco use have declined due to improved sanitation, nutrition programs, and tobacco control policies. For example, enhanced agricultural practices and food distribution systems have reduced malnutrition, while tobacco control policies such as taxation and advertising bans have decreased smoking prevalence. These factors have strengthened immune systems and reduced the burden of respiratory diseases [35,36].

Metabolic risks such as high BMI and FPG present a more complex situation. Although their ASMR and ASDR have declined, absolute deaths and DALYs have risen due to population growth and aging. Geographic disparities are pronounced, with Lesotho experiencing the largest increase in ASMR attributable to high BMI, possibly due to changing dietary patterns and reduced physical activity. In contrast, Hungary's significant reduction in high BMI-related ASMR may be attributed to successful public health initiatives promoting healthy lifestyles [37].

In summary, the decline in ASMR and ASDR for respiratory infections and tuberculosis attributable to different risk factors is shaped by a multitude of factors, including public health interventions, socio-economic development, population dynamics, and geographic disparities. Understanding these relationships can inform more targeted public health strategies to address the disease burden caused by these risk factors.

Geographic disparities in disease burden were pronounced. Lesotho exhibited the largest increase in ASMR attributable to high BMI, with an AAPC of 3.92 (95% CI: 3.58 to 4.26). In contrast, Hungary achieved the steepest reduction in high BMI-related ASMR (AAPC: − 7.4, 95% CI: − 7.99 to − 6.8). Stratification by gender and age revealed further inequities. Males experienced a disproportionately higher burden from behavioral risks, with ASMR for tobacco use 3.6 times greater than that of females. Children under 5 years of age were particularly vulnerable to environmental risks, as evidenced by the highest AAPC values among all age groups for secondhand smoke exposure (− 5.96, 95%

CI: − 6.10 to − 5.82), air pollution (− 4.76, 95% CI: − 5.00 to − 4.52) and unsafe water, sanitation, and handwashing (− 4.55, 95% CI: − 4.80 to − 4.29).

Prior evidence has demonstrated an inverse association between the SDI and burdens of infectious diseases [38,39]. The findings of this study further show a negative association between the burden of respiratory infections and tuberculosis attributable to 9 risk factors, particularly for traditional risks such as malnutrition (− 0.8408, 95% CI: − 0.8616 to − 0.8171) and air pollution (− 0.8728, 95% CI: − 0.8897 to − 0.8535). The observed male predominance in tobacco- and alcohol-related mortality aligns with established behavioral epidemiology literature [40,41]. However, this study advances this understanding by uncovering synergistic interactions between these behavioral risks and age-specific factors. The males exhibited a 3.6-fold higher tobacco-attributable ASMR compared to females, with this disparity progressively widening from age 30 onwards. This age-dependent escalation suggests that cumulative exposure to behavioral risks, compounded by biological and social determinants, impacts male populations in later adulthood.

While this analysis benefits from the robust methodologies of the GBD 2021 study, several limitations warrant consideration. First, residual confounding from unmeasured factors—such as genetic predispositions, healthcare quality, and environmental co-exposures—could bias risk-attributable fractions, potentially obscuring the true magnitude of certain risk-outcome relationships. To mitigate this, future studies should incorporate genetic testing and detailed environmental monitoring to better control for these factors. Second, the reliance on ecological correlations with the SDI limits the ability to infer causality, as SDI aggregates multiple socioeconomic and demographic factors that may independently influence health outcomes. To address this, integrating individual-level data with SDI metrics is recommended in future research to enhance causal inference. Finally, the interplay between overlapping risks, such as the potential synergism between tobacco use and air pollution, remains unaddressed in this analysis. Mechanistic studies are needed to disentangle these complex interactions and refine risk attribution models. Prioritizing funding for laboratory and cohort studies that can investigate these synergistic effects is recommended. Additionally, policymakers should consider implementing multifaceted public health interventions that target multiple risk factors simultaneously, such as combining tobacco cessation programs with initiatives to improve air quality. These strategies can help reduce the burden of respiratory infections and tuberculosis more effectively.

The rising burden of metabolic risks, despite declining ASMR and ASDR, urgently calls for dual interventions: enhancing traditional disease control measures while simultaneously addressing the epidemics of obesity and diabetes. Regionally, policies should focus on context-specific risks, such as implementing tobacco taxation in high-middle SDI regions, improving air quality in South Asia, and launching nutrition programs in Sub-Saharan Africa. Future research should explore the biological mechanisms underlying how metabolic dysregulation which increases susceptibility to respiratory infections and tuberculosis, as well as conduct cost-benefit analyses of targeted interventions.

This study underscores the impact of various risk factors on the burden of respiratory infections and tuberculosis, revealing distinct trends by age, gender, SDI, and region. These findings highlight the necessity for tailored interventions and policies to address the diverse risk factors and health disparities across different regions and populations.

Conclusions

Respiratory infections and tuberculosis remain the leading global causes of morbidity and mortality, yet the dynamics of their risk factors across diverse populations are poorly characterized. Data from the GBD 2021 study across 204 countries (1990–2021) was used to quantify the burden of respiratory infections and tuberculosis attributable to 9 key risk factors. Traditional risks, such as deaths and DALYs attributable to malnutrition and air pollution, declined globally. In contrast, metabolic risks, including high BMI and FPG, increased, particularly in low-SDI regions. Geographic disparities were pronounced: Lesotho saw the largest increase in ASMR for high BMI (AAPC: 3.92 [95% CI: 3.58 to 4.26]), while Hungary achieved significant reductions (AAPC: −7.4 [95% CI: −7.99 to −6.8]). Males experienced a higher burden from behavioral risks, with tobacco ASMR 3.6-fold higher than females. Children under 5 years were particularly vulnerable to environmental risks. The findings advocate for precision interventions to address the dual burdens of traditional and emerging risks, thereby advancing global health equity.

Acknowledgements

We thank the GBD research team for data support and all the contributors to this study.

Data availability statement

All data used in this research are publicly available at the Global Burden of Disease (GBD) 2021 (https://vizhub.healthdata.org/gbd-results/).

Authors contributions

Conceptualization: SC, SX; formal analysis: JJ; interpretation: YS, HZ; writing: SC, SX; visualization: SC; supervision: SX. All authors reviewed the manuscript.

Corresponding author

Sicheng Xu
No. 137, Liyushan South Road, Urumqi,13 Xinjiang, China.
Email: xu_sicheng@126.com

Conflict of interest

No conflict of interest is declared.

References

1. Zar HJ, Ferkol TW (2014) The global burden of respiratory disease-impact on child health. Pediatr Pulmonol 49: 430–434. doi: 10.1002/ppul.23030.
2. Krishnamoorthy Y, Selvaraja C, Govindan D (2025) Determinants of delays in the tuberculosis care pathway and adverse treatment outcomes in Chennai, South India: a retrospective cohort study. Clin Epidemiol Glob Health 35: 102123. doi: 10.1016/j.cegh.2025.102123.
3. Chang AB, Kovesi T, Redding GJ, Wong C, Alvarez GG, Nantanda R, Beltetón E, Bravo-López M, Toombs M, Torzillo PJ, Gray DM. (2024) Chronic respiratory disease in indigenous peoples: a framework to address inequity and strengthen respiratory health and health care globally. Lancet Respir Med 12: 556–574. doi: 10.1016/S2213-2600(24)00008-0.
4. Oliphant NP, Manda S, Daniels K, Odendaal WA, Besada D, Kinney M, White Johansson E, Doherty T (2021) Integrated community case management of childhood illness in low- and middle-income countries. Cochrane Database Syst Rev 10: CD012882. doi: 10.1002/14651858.CD012882.pub2.
5. Bălă G-P, Râjnoveanu R-M, Tudorache E, Motișan R, Oancea C (2021) Air pollution exposure-the (in)visible risk factor for respiratory diseases. Environ Sci Pollut Res Int 28: 19615–19628. doi: 10.1007/s11356-021-13208-x.
6. Bates MN, Khalakdina A, Pai M, Chang L, Lessa F, Smith KR (2007) Risk of tuberculosis from exposure to tobacco smoke: a systematic review and meta-analysis. Arch Intern Med 167: 335–342. doi: 10.1001/archinte.167.4.335.
7. Mengistu DA (2021) Public health implications of heavy metals in foods and drinking water in Ethiopia (2016 to 2020): systematic review. BMC Public Health 21: 2114. doi: 10.1186/s12889-021-12189-3.
8. Liu Y, Pleasants RA, Croft JB, Lugogo N, Ohar J, Heidari K, Strange C, Wheaton AG, Mannino DM, Kraft M (2015) Body mass index, respiratory conditions, asthma, and chronic obstructive pulmonary disease. Respir Med 109: 851–859. doi: 10.1016/j.rmed.2015.05.006.
9. Meng F, Lan L, Wu G, Ren X, Yuan X, Yang M, Chen Q, Peng X, Liu D (2023) Impact of diabetes itself and glycemic control status on tuberculosis. Front Endocrinol (Lausanne) 14: 1250001. doi: 10.3389/fendo.2023.1250001.
10. Xu G, Hu X, Lian Y, Li X (2023) Diabetes mellitus affects the treatment outcomes of drug-resistant tuberculosis: a systematic review and meta-analysis. BMC Infect Dis 23: 813. doi: 10.1186/s12879-023-08765-0.
11. Zhang W, Yu H, Shang J, Liu T, Ma J, Gu X (2015) Association between dietary habits and recurrent respiratory infection in children: a case-control study. J Tradit Chin Med Sci 2: 105–110. doi: 10.1016/j.jtcms.2016.01.003.
12. Leveille SG, Gray S, LaCroix AZ, Ferrucci L, Black DJ, Guralnik JM (2000) Physical inactivity and smoking increase risk for serious infections in older women. J Am Geriatr Soc 48: 1582–1588. doi: 10.1111/j.1532-5415.2000.tb03867.x.
13. Simet SM, Sisson JH (2015) Alcohol's effects on lung health and immunity. Alcohol Res 37: 199–208. doi: 10.35946/arcr.v37.2.05.
14. Zhang T, Zhang J, Wei L, Liang H, Zhang J, Shi D, Wang Z (2023) The global, regional, and national burden of tuberculosis in 204 countries and territories, 1990–2019. J Infect Public Health 16: 368–375. doi: 10.1016/j.jiph.2023.01.014.
15. Yang H, Ruan X, Li W, Xiong J, Zheng Y (2024) Global, regional, and national burden of tuberculosis and attributable risk factors for 204 countries and territories, 1990–2021: a systematic analysis for the Global Burden of Diseases 2021 study. BMC Public Health 24: 3111. doi: 10.1186/s12889-024-20664-w.
16. Gilmore AB, Fooks G, Drope J, Bialous SA, Jackson RR (2015) Exposing and addressing tobacco industry conduct in low-income and middle-income countries. Lancet 385: 1029–1043. doi: 10.1016/S0140-6736(15)60312-9.
17. Theilmann TM, Lemp JM, Winkler V, Manne-Goehler J, Marcus ME, Probst C, Lopez-Arboleda WA, Ebert C, Bommer C, Mathur M, Andall-Brereton G, Bahendeka SK, Bovet P, Farzadfar F, Ghasemi E, Mayige MT, Saeedi Moghaddam S, Mwangi KJ, Naderimagham S, Sturua L, Atun R, Davies JI, Bärnighausen T, Vollmer S, Geldsetzer P (2022) Patterns of tobacco use in low and middle income countries by tobacco product and sociodemographic characteristics: nationally representative survey data from 82 countries. BMJ 378: e067582. doi: 10.1136/bmj-2021-067582.
18. Shenoy S, Sharma P, Rao A, Aparna N, Adenikinju D, Iloegbu C, Pateña J, Vieira D, Gyamfi J, Peprah E (2023) Evidence-based interventions to reduce maternal malnutrition in low and middle-income countries: a systematic review. Front Health Serv 3: 1155928. doi: 10.3389/frhs.2023.1155928.
19. Danaei G, Singh GM, Paciorek CJ, Lin JK, Cowan MJ, Finucane MM, Farzadfar F, Stevens GA, Riley LM, Lu Y, Rao M, Ezzati M, Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group (2013) The global cardiovascular risk transition: associations of four metabolic risk factors with national income, urbanization, and Western diet in 1980 and 2008. Circulation 127: 1493–1502, 1502e1–8. doi: 10.1161/CIRCULATIONAHA.113.001470.
20. Wells JC, Sawaya AL, Wibaek R, Mwangome M, Poullas MS, Yajnik CS, Demaio A (2020) The double burden of malnutrition: aetiological pathways and consequences for health. Lancet 395: 75–88. doi: 10.1016/S0140-6736(19)32472-9.
21. Han MK, Arteaga-Solis E, Blenis J, Bourjeily G, Clegg DJ, DeMeo D, Duffy J, Gaston B, Heller NM, Hemnes A, Henske EP, Jain R, Lahm T, Lancaster LH, Lee J, Legato MJ, McKee S, Mehra R, Morris A, Prakash YS, Stampfli MR, Gopal-Srivastava R, Laposky AD, Punturieri A, Reineck L, Tigno X, Clayton J (2018) Female sex and gender in lung/sleep health and disease. Increased understanding of basic biological,

pathophysiological, and behavioral mechanisms leading to better health for female patients with lung disease. Am J Respir Crit Care Med 198: 850–858. doi: 10.1164/rccm.201801-0168WS.
22. Siegfried JM (2022) Sex and gender differences in lung cancer and chronic obstructive lung disease. Endocrinology 163. doi: 10.1210/endocr/bqab254.
23. Bartoli CR, Godleski JJ, Verrier RL (2011) Mechanisms mediating adverse effects of air pollution on cardiovascular hemodynamic function and vulnerability to cardiac arrhythmias. Air Qual Atmos Health 4: 53–63. doi: 10.1007/s11869-010-0091-6.
24. Bowatte G, Lodge C, Lowe AJ, Erbas B, Perret J, Abramson MJ, Matheson M, Dharmage SC (2015) The influence of childhood traffic-related air pollution exposure on asthma, allergy and sensitization: a systematic review and a meta-analysis of birth cohort studies. Allergy 70: 245–256. doi: 10.1111/all.12561.
25. GBD 2021 Diseases and Injuries Collaborators (2024) Global incidence, prevalence, years lived with disability (YLDs), disability-adjusted life-years (DALYs), and healthy life expectancy (HALE) for 371 diseases and injuries in 204 countries and territories and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. Lancet 403: 2133–2161. doi: 10.1016/S0140-6736(24)00757-8.
26. GBD 2021 Risk Factors Collaborators (2024) Global burden and strength of evidence for 88 risk factors in 204 countries and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. Lancet 403: 2162–2203. doi: 10.1016/S0140-6736(24)00933-4.
27. GBD Tuberculosis Collaborators (2018) Global, regional, and national burden of tuberculosis, 1990–2016: results from the Global Burden of Diseases, Injuries, and Risk Factors 2016 Study. Lancet Infect Dis 18: 1329–1349. doi: 10.1016/S1473-3099(18)30625-X.
28. GBD 2019 Tuberculosis Collaborators (2022) Global, regional, and national sex differences in the global burden of tuberculosis by HIV status, 1990–2019: results from the Global Burden of Disease Study 2019. Lancet Infect Dis 22: 222–441. doi: 10.1016/S1473-3099(21)00449-7.
29. Simkovich SM, Goodman D, Roa C, Crocker ME, Gianella GE, Kirenga BJ, Wise RA, Checkley W (2019) The health and social implications of household air pollution and respiratory diseases. NPJ Prim Care Respir Med 29: 12. doi: 10.1038/s41533-019-0126-x.
30. Berthon BS, Wood LG (2015) Nutrition and respiratory health-feature review. Nutrients 7: 1618–1643. doi: 10.3390/nu7031618.
31. Wang MX, Koh J, Pang J (2019) Association between micronutrient deficiency and acute respiratory infections in healthy adults: a systematic review of observational studies. Nutr J 18: 80. doi: 10.1186/s12937-019-0507-6.
32. Bartram J, Lewis K, Lenton R, Wright A (2005) Focusing on improved water and sanitation for health. Lancet 365: 810–812. doi: 10.1016/S0140-6736(05)17991-4.
33. Qureshi ME, Dixon J, Wood M (2015) Public policies for improving food and nutrition security at different scales. Food Secur 7: 393–403. doi: 10.1007/s12571-015-0443-z.
34. Chugh A, Arora M, Jain N, Vidyasagaran A, Readshaw A, Sheikh A, Eckhardt J, Siddiqi K, Chopra M, Mishu MP, Kanaan M, Rahman MA, Mehrotra R, Huque R, Forberger S, Dahanayake S, Khan Z, Boeckmann M, Dogar O (2023) The global impact of tobacco control policies on smokeless tobacco use: a systematic review. Lancet Glob Health 11: e953–968. doi: 10.1016/S2214-109X(23)00205-X.
35. Hasani WSR, Musa KI, Cheng KY, Dass SC (2024) Exploring the trend of age-standardized mortality rates from cardiovascular disease in Malaysia: a joinpoint analysis (2010–2021). BMC Public Health 24: 2519. doi: 10.1186/s12889-024-19103-7.
36. Liu Q, Su J, Liang Y, He X (2025) Global burden and trend of stroke attributable to metabolic risks among young adults (20–39 years old) from 1990 to 2021. Front Cardiovasc Med 12: 1561052. doi: 10.3389/fcvm.2025.1561052.
37. Liu Y, Yan M (2023) Trends in all causes and cause specific mortality attributable to ambient particulate matter pollution in China from 1990 to 2019: a secondary data analysis study. PLoS One 18: e0291262. doi: 10.1371/journal.pone.0291262.
38. Li XC, Zhang YY, Zhang QY, Liu JS, Ran JJ, Han LF, Zhang XX (2024) Global burden of viral infectious diseases of poverty based on Global Burden of Diseases Study 2021. Infect Dis Poverty 13: 71. doi: 10.1186/s40249-024-01234-z.
39. Bao Y, Li Y, Zhou Y, Qiang N, Li T, Zhang Y, Chong MKC, Zhao S, Deng X, Zhang X, Han L, Ran J (2024) Global burden associated with rare infectious diseases of poverty in 2021: findings from the Global Burden of Disease Study 2021. Infect Dis Poverty 13: 85. doi: 10.1186/s40249-024-01249-6.
40. Chen Z, Peto R, Zhou M, Iona A, Smith M, Yang L, Guo Y, Chen Y, Bian Z, Lancaster G, Sherliker P, Pang S, Wang H, Su H, Wu M, Wu X, Chen J, Collins R, Li L, China Kadoorie Biobank (CKB) collaborative group (2015) Contrasting male and female trends in tobacco-attributed mortality in China: evidence from successive nationwide prospective cohort studies. Lancet 386: 1447–1456. doi: 10.1016/S0140-6736(15)00340-2.
41. McCartney G, Mahmood L, Leyland AH, Batty GD, Hunt K (2011) Contribution of smoking-related and alcohol-related deaths to the gender gap in mortality: evidence from 30 European countries. Tob Control 20: 166–168. doi: 10.1136/tc.2010.037929.